

# SEARCH REQUEST FORM

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B43

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\*\*\*\*\*

Please provide a detailed statement of the search topic, and describe as specifically as possible the subject matter to be searched. Include the elected species or structures, keywords, synonyms, acronyms, and registry numbers, and combine with the concept or utility of the invention. Define any terms that may have a special meaning. Give examples or relevant citations, authors, etc, if known. Please attach a copy of the cover sheet, pertinent claims, and abstract.

Title of Invention: METHODS TO CONTROL HEAT TRANSFER IN FLUIDS CONTAINING  
DRAW-REDUCING ADDITIVES  
Inventors (please provide full names): MATHIAS, ERIC; GASLISVIC, KAZIMIR  
Earliest Priority Filing Date: 2 SEPT 1999

\*For Sequence Searches Only\* Please include all pertinent information (parent, child, divisional, or issued patent numbers) along with the appropriate serial number.

SEE ATTACHED

= PCT/WO 00/14455 ?

STAFF USE ONLY		Type of Search	Vendors and cost where applicable
Searcher: <u>Emory D. Brown</u>	NA Sequence (#)	STN	<u>x 98.62</u>
Searcher Phone #: <u>305 8587</u>	AA Sequence (#)	Dialog	<u>x 1009.14</u>
Searcher Location: <u>CP 2 218</u>	Structure (#)	Questel/Orbit	
Date Searcher Picked Up: <u>5/17/04 345P</u>	Bibliographic	Dr.Link	<u>x</u>
Date Completed: <u>5/18/04 245P</u>	Litigation	Lexis/Nexis	
Searcher Prep & Review Time: <u>210 min</u>	Fulltext	Sequence Systems	<u>x</u>
Clerical Prep Time: <u>0</u>	Patent Family	WWW/Internet	<u>x SCIRUS/SCIENCE DIRECT</u>
Online Time: <u>210 min</u>	Other	Other (specify)	

Set	Items	Description
S1	75286	(HEAT? OR THERM?) ( ) (EXCHANG? OR TRANSFER?)
S2	118373	SURFACTANT? OR SURFACE ( ) ACTIVE OR SURFACEACTIVE ( ) AGENT?
S3	191031	ANION? OR CATION? OR COUNTERION? OR NONION? OR (AN OR CAT - OR COUNTER OR NON) ( ) (ION OR IONS OR IONIC?) OR TEMPERATURE ( ) I- NDEPENDENT OR (NON OR "NOT") ( ) TEMPERATURE ( ) DEPENDENT
S4	347371	MOLECUL? OR MICELL? OR MICROSTRUCTUR? OR MICRO ( ) STRUCTUR?
S5	150055	DRAG OR FRICTION?
S6	605365	WIRE? OR MESH?? OR FILTER??
S7	361445	REBUIL? OR RECOVER? OR RECONSTITUT? OR RECOMPOS? OR REFORM? OR REPAIR? OR REPAR? OR SELFREPAIR? OR REASSEMBL? OR SELFASS- EMBL? OR SELF ( ) (REPAR? OR ASSEMBL? OR REPAIR?)
S8	580485	BREAK? OR FRACTUR? OR DISRUPT? OR TURBULEN? OR DEGRAD? OR - DISTURB? OR ROIL? OR STRESS? OR SHEAR?
S9	238439	BREAK? ( ) UP OR ENLIVEN? OR INVIGORAT? OR FOAM? OR FROTH? OR EDDY? OR SWIRL? OR VORTEX? OR VORTIC? OR HELIX? OR HELIC?
S10	448114	PUMP? OR VALV? OR FLOW ( ) GEOMET? OR TEMPERATURE ( ) JUMP? OR H- YDRODYNAM? OR HYDRON? OR ULTRASONIC? OR ULTRASOUND? OR ELECTR- OMAGNET?
S11	52042	IC=(F24H? OR C10M? OR C09K? OR F28F? OR F28D? OR C11D?)
S12	6147	S1 AND S2
S13	195	S12 AND S1(10N)S2
S14	150	S13 AND (S3 OR S11)
S15	195	S13:S14
S16	42	S15 AND S5
S17	148	S15 AND S4
S18	36	S16 AND S17
S19	1	S17 AND S4(5N)S7
S20	1	S17 AND S4(10N)S7
S21	137	S17 AND S8:S10
S22	35	S21 AND S5
S23	42	S16 OR S18:S20 OR S22
S24	42	IDPAT (sorted in duplicate/non-duplicate order)

? show files

File 348:EUROPEAN PATENTS 1978-2004/May W01

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File 349:PCT FULLTEXT 1979-2002/UB=20040513,UT=20040506.

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24/3,K/5 (Item 5 from file: 348)  
DIALOG(R)File 348:EUROPEAN PATENTS  
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00771064

USE OF ALKOXYLATED ALKANOLAMIDE TOGETHER WITH AN IONIC SURFACTANT AS  
FRICTION -REDUCING AGENT

VERWENDUNG VON ALKOXYLIERTEM ALKANOLAMID IN KOMBINATION MIT IONISCHEM  
TENSID ALS REIBUNGSREDUZIERENDES MITTEL

UTILISATION D'UN ALKANOLAMIDE ALCOXYLE EN COMBINAISON AVEC UN AGENT  
TENSIOACTIF IONIQUE COMME AGENT DE REDUCTION DE FRICTION

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PRIORITY (CC, No, Date): SE 943363 941003

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C10M-105/68

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No A-document published by EPO

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CLAIMS B	(English)	200247	408
CLAIMS B	(German)	200247	391
CLAIMS B	(French)	200247	473
SPEC B	(English)	200247	2881
Total word count - document A			0
Total word count - document B			4153
Total word count - documents A + B			4153

USE OF ALKOXYLATED ALKANOLAMIDE TOGETHER WITH AN IONIC SURFACTANT AS  
FRICTION -REDUCING AGENT

... UN ALKANOLAMIDE ALCOXYLE EN COMBINAISON AVEC UN AGENT TENSIOACTIF  
IONIQUE COMME AGENT DE REDUCTION DE FRICTION

INTERNATIONAL PATENT CLASS: C09K-003/00 ...

... C10M-105/68

...SPECIFICATION The present invention relates to the use of an alkoxyated  
alkanolamide together with an ionic **surfactant** in a water-base system  
for reducing the flow resistance between a solid surface and the  
water-base liquid system.

**Surfactants** with the ability to form extremely long, cylindrical  
**micelles** have, in recent years, attracted a great interest as **friction**  
-reducing additives to systems with circulating water, especially those  
destined for heat or cold distribution...

...maintain a laminar flow in the conduits, one wishes at the same time to  
have **turbulence** in the **heat exchangers** to achieve therein a high

heat transfer per unit area.

The rod-shaped **micelles** are distinguished by operating in a fairly disorderly fashion at low Reynold's numbers (below...

...very slight effect on the flow resistance. At higher Reynold's numbers (above 104)), the **micelles** are paralleled and result in a **friction** reduction very close to that which is theoretically possible. At even higher Reynold's numbers (e.g. above 105)), the **shear** forces in the liquid become so high that the **micelles** start to get torn and the **friction** -reducing effect rapidly decreases as the Reynold's number increases above this value.

The range of Reynold's numbers within which the **surface - active** agents have a maximum **friction** -reducing effect is heavily dependent on the concentration, the range increasing with the concentration. By choosing the right concentration of **surface - active** agents and suitable flow rates in tubings and **heat exchangers**, it is thus possible to establish a laminar flow in the tubes and **turbulence** in the **heat exchangers**. Thus, the dimensions of both the tubes and the exchangers can be kept at a low level, or the number of **pump** stations, and consequently the **pump** work, can alternatively be reduced while retaining the same tubular dimensions.

The **surface - active** agents most commonly used as **friction** -reducing additives to circulating water systems for heat or cold distribution are of the type...

...which may either be saturated or contain one or more double bonds. This type of **surface - active** agent functions satisfactorily already at a concentration of 0.5-1 g/l, but is **degraded** very slowly, both aerobically and anaerobically, and further is highly toxic to marine organisms.

Since...

...2-4 carbon atoms and n is 3-12 are capable of forming long cylindrical **micelles** in water and thus reduce the **friction** in water-based system. These products are easily **degradable** and function excellently in deionized water especially at low temperatures. However, the **friction** -reducing effects are hampered in hard water and by the presence of high amounts of electrolytes. Further the temperature range for their optimal **friction** -reducing effect will be rather narrow, sometimes as small as 10 degrees centigrade.

It has...

...surprisingly been found that mixtures of the alkoxyated alkanolamides described above in combination with ionic **surfactants** can give a water-base liquid system the desired **friction** -reducing properties in both hard and salt water and also a substantially increased temperature range...

...the optimal effect, e.g. 30 degrees centigrade. It is possible to obtain a satisfactory **friction** -reducing effect even when the hardness is as high as 500 ppm (CaCO<sub>3</sub>)) and the...

...the water-base liquid system.

The weight ratio between the alkoxyated alkanolamide and the ionic **surfactant** may be varied between 100:1 and 1:2, preferably 50:1 and 1:1. Besides the structure of the two **surface active** components the weight ratio also depends on the hardness and salt content of the water...

...the water-base liquid system. The total amount of the alkoxyated alkanolamide and the ionic **surfactant** may vary within wide limits depending on the conditions, but is generally 100-10 000...



- ...the water-base liquid system consists of water. The combination of alkoxyated alkanolamide and ionic **surfactant** is especially suited for use in water-base systems flowing in long conduits, e.g...alkoxyated alkanolamide is to operate but also by the kind and amount of the ionic **surfactant** which will be included in the mixture and the hardness and salt content of the...
- ...large hydrocarbon group and a low degree of alkoxylation will need a rather hydrophilic ionic **surfactant**, i.e. an ionic **surfactant** with a short to moderate hydrocarbon group and a large hydrophilic group or even two...
- ...hydrophobic, i.e. it creates a demand for either a higher amount of the ionic **surfactant** or a more hydrophilic ionic **surfactant**. A convenient way to find out the right proportion between the ionic **surfactant** and the alkoxyated alkanolamide is to disperse the latter in the water that shall be...
- ...in the planned operational temperature range and then add successively a solution of the ionic **surfactant** until the dispersed alkoxyated alkanolamide just has been solubilized.
- The ionic **surfactant** may be chosen from any of the known classes, i.e. **anionic**, **cationic**, amphoteric or zwitterionic.
- Suitable **anionic surfactants** according to the invention are fatty acid soaps,  $R_1(COO^-)Me^+$ , alkylpolyglycoethersulphates  $R_1O(Cx...$
- ...carbon atoms, Ar an aromatic hydrocarbon group preferably with 6 carbon atoms,  $Me^+$  a monovalent **cation**, x is a number from 2-4 and n is a number from 1-4.
- Suitable **cationic surfactants** according to the invention are primary ammonium salts  $R_1(NH_3^+)A^-$ , secondary ammonium salts  $R_1...$
- ...given above, R' is methyl, ethyl, propyl or hydroxyethyl group and  $A^-$  is a monovalent **anion**.
- Quaternary alkylammonium compounds such as lauryl- or myristyltrialkylammoniumhalogenid can also be used but are not...
- ...to their slow biodegradation and comparatively high toxicity against marine organisms.
- Suitable amphoteric and zwitterionic **surfactants** are those containing
- i) one or more, preferably one or two, monovalent hydrophobic groups, preferably...
- ...ammonium groups
- iii) one or more, preferably one or two carboxylic groups and having a **molecular** weight of less than 1400. The amphoteric or zwitterionic **surfactants** may also contain one or more **nonionic**, hydrophilic groups, such as hydroxyl groups and ether groups. Their effect on the environment is low, especially in comparison with the previous used quaternary **cationic friction**-reducing agents.
- Example of suitable amphoteric and zwitterionic **surfactants** are those with the formulae wherein  $R_3$  is a hydrocarbon group having 7-24 carbon ...group, and p is 1 or 2.
- Apart from the alkoxyated alkanolamide and the ionic **surfactant** the water-base system may contain a number of conventional components, such as rust-preventing...
- ...solubilisers, such as diethylene glycol monobutyl ethers, which may affect the cloud point of the **surfactant** mixture in the water-base

system quite considerably.

The present invention will now be further illustrated with the aid of the following examples.

#### Test procedure

The **friction** -reducing properties of the products of the invention and the products according to the prior...

...15 mm, the stirrer started at full speed, 1400 rpm, and the depth of the **vortex** formed in the solution was recorded at various temperatures while the solution temperature increased to room temperature during 15 mins.

When no **vortex** could be detected (recorded as 0 mm), it is known by experience that this indicate good **friction** reducing properties.

If on the other hand no efficient additive was present, e.g. for pure water the **vortex** reached down to the stirring magnet and the result was recorded as 35 mm.

Loop...

...of 8 mm and the other having an inner diameter of 10 mm. Water was **pumped** through the tube loop by a centrifugal **pump**, which was driven by a frequency-controlled motor, for continuous adjustment of the flow rate...

...rotameter.

The straight parts of the tube loop had outlets which, with the aid of **valves**, could in turn be connected to a differential pressure gauge whose other side was all...

...tube loop. Further, the tube loop was heat-insulated, and the suction side of the **pump** was connected to a thermostatically controlled container with a volume of 20 l, to which...

...for each flow rate. The pressure differences thus measured were then converted into Moody's **friction** factory Y and are shown in the examples as a function of the Reynold's...

...examples also state the corresponding Prandtl number and Virk number. The former corresponds to the **friction** factor of water only, i.e. with **turbulence**, and the latter corresponds to flow without **turbulence**, i.e. a laminar flow.

Examples 1-4

These examples were carried out according to...

...linoleic acid and 10% linolenic acid the rest being mainly palmitic and stearic acids.

As **anionic surfactants** have been used a technical laurylpolyglycoethersulphate and a technical laurylsulphate. In both cases is the...

...given in the table below:

The test results are given as the depth of the **vortex** formed in mm at the stirrer speed of 1400 r.p.m. The asterisk \* means...

...invention have a significant stabilizing effect on the water level in immediate vicinity of a **turbulent** zone and may thus be expected to have good **friction** -reducing ability on water flowing in a tube.

Example 5

This example was carried out...corrosion inhibitor salts are lacking.  
Through a substantial decrease of the amount of added ionic **surfactant** it is still possible to make a composition according to the invention with good stabilizing...  
...with a composition according to the invention it can clearly be seen that a substantial **friction** -reducing effect can be achieved in the temperature range 7-21(degree)C in a...

...CLAIMS having 2-4 carbon atoms and n is 2-12, and at least one ionic **surfactant** in a weight proportion between the alkoxyated alkanolamide and the ionic **surfactant** from 100:1 to 1:2, for producing a water-base liquid system with reduced...

...in that the crystallization temperature for the mixture of the alkoxyated alkanolamide and the ionic **surfactant** is below the lowest temperature of the water-base system.

6. Use as claimed in...

...30(degree)C.

7. Use as claimed in claim 2, characterized in that the ionic **surfactant** is an **anionic surfactant** is selected from the group consisting of fatty acid soaps, R1)COO-)Me+), alkylpolyglycolethersulphates R1 ...

...hydrocarbon chain with 8-22 carbon atoms, Ar an aromatic hydrocarbon group, Me+) a monovalent **cation** , x is a number from 2-4 and n is a number from 1-4.

8. Use as claimed in claim 2, characterized in that the **cationic surfactant** is selected from the group consisting of a primary ammonium salts R1))+)NH3))A-), secondary...

...given above, R' is methyl, ethyl, propyl or hydroxyethyl group and A-) is a monovalent **anion** .

9. Use as claimed in claim 2, characterized in that the amphoteric or zwitterionic **surfactant** contains

i) one or more monovalent hydrophobic groups, forming a hydrophobic portion containing 10-36...

...amine groups or quaternary ammonium groups

iii) one or more carboxylic groups and has a **molecular** weight of less than 1400.

10. Use as claimed in any of claims 1-9, characterized in that the mixture of the alkoxyated alkanolamide and the ionic **surfactant** is added in an amount of 0.1-10 kg/m3) of the water-base...

24/3,K/10 (Item 10 from file: 349)  
DIALOG(R)File 349:PCT FULLTEXT  
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00293139

USE OF AN AMPHOTERIC SURFACTANT AS A FRICTION -REDUCING AGENT  
UTILISATION D'UN TENSIOACTIF AMPHOTERE EN TANT QU'AGENT REDUCTEUR DE  
FRICTION

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Inventor(s):

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USE OF AN AMPHOTERIC SURFACTANT AS A FRICTION -REDUCING AGENT  
UTILISATION D'UN TENSIOACTIF AMPHOTERE EN TANT QU'AGENT REDUCTEUR DE  
FRICTION

Main International Patent Class: C10M

International Patent Class: C10M ; ...

... C10M ; ...

... C10M ; ...

... C10M ; ...

... C10M ;

Fulltext Availability:

Detailed Description  
Claims

English Abstract

Amphoteric **surfactants** containing one or more, preferably one or two,  
monovalent hydrophobic groups forming a hydrophobic portion...

...amine groups; and one or more, preferably one or two, carboxylic groups;  
and having a **molecular** weight of less than 1400, or a salt thereof, as  
a **friction** reducing agent in a water-base liquid system have been found  
have a **friction** reducing effect when added to water-base liquid system  
like **heat transfer** system.

French Abstract

...qu'un ou plusieurs, de preference un ou deux, groupe(s)  
carboxylique(s), leur poids **moleculaire** etant inferieur a 1400. On a  
constate que ces tensioactifs utilises en tant qu'agents reducteurs de  
**friction** dans un systeme liquide a base d'eau presentaient un effet  
reducteur de **friction** lorsqu'on les ajoutait a un tel systeme, comme un  
systeme de transfert thermique.

Detailed Description

USE OF AN AMPHOTERIC SURFACTANT AS A FRICTION -REDUCING AGENT  
The present invention relates to the use of an amphoteric surfactant in a water-base system for reducing the flow resistance between a solid surface...

...that the flow resistance of a liquid in a conduit is largely due to the turbulence that arises at the conduit wall, Surfactants with the ability to form extremely long, cylindrical micelles have, in recent years, attracted a great interest as friction-reducing additives to systems with circulating water, especially those destined for heat distribution, An...

...maintain a laminar flow in the conduits, one wishes at the same time to have turbulence in the heat exchangers to achieve therein a high heat transfer per unit area.

The rod-shaped micelles are distinguished by operating in a fairly disorderly fashion at low Reynold's numbers (below...

...effect on the flow resistance, At higher Reynold's numbers (above 10<sup>4</sup>), the micelles are paralleled and result in a friction reduction very close to that which is theoretically possible, At even higher Reynold's numbers (e.g, above 10<sup>5</sup>), the shear forces in the liquid become so high that the micelles start to get torn and the friction reducing effect rapidly decreases as the Reynold's numbers increase.

The range of Reynold's numbers within which the surface active agents have a maximum friction-reducing effect is among others dependent on the concentration, the range increasing with the concentration,

By choosing the right concentration of surface - active agents and suitable flow rates in tubings and heat exchangers, it is thus possible to establish a laminar flow in the tubes and turbulence in the heat exchangers. Thus, the dimensions of both the tubes and the exchangers can be kept at a low level, or the number of pump stations, and consequently the pump work, can alternatively be reduced while retaining the same tubular dimensions.

Most of the surface - active agents hitherto used as frictionreducing additives to circulating water system - mainly destined for heat distribution - are cationic surfactants like C 16 alkyltrimetyl ammonium salicylate, However,, this type of surface - active agent is slowly degraded, both aerobically and anaerobically, and is highly toxic to marine organisms. since heat-distribution systems...

...to the environment,

In the Swedish Patent publication No 467 826 it is disclosed that nonionic, alkoxylated alkanolamides may be used as friction-reducing agents, These nonionic surfactants have an excellent friction reducing effect at low or moderate temperatures but at higher temperatures the friction reducing effect is less satisfactory and may even be lost.

It has now surprisingly been found that a water-soluble amphoteric surfactant containing

i) one or more, preferably one or two, monovalent hydrophobic groups, preferably hydrocarbon...

...groups and

iii) one or more, preferably one or two carboxylic groups and having a **molecular** weight of less than 1400, preferably less than 800, or a salt thereof has the ability to form long cylindrical **micelles**. The amphoteric **surfactant** may also contain one or more **nonionic**, hydrophilic groups, such as hydroxyl groups and ether groups. This type of amphoteric **surfactant** has an excellent **friction**-reducing effect well adapted for aqueous **heat transfer** systems. Furthermore, the effect of the amphoteric **surfactant** on the environment is low, especially in comparison with the previous used **cationic friction**-reducing agents. The amount of the amphoteric friction-reducing agent may vary within wide...

...depending on

the conditions but generally is 100 000 g/m<sup>3</sup> of the aqueous **heat transfer** liquid,

Suitable amphoteric **surfactants** to be used as **friction** reducing agents are those **surfactants** which have the formula

R<sub>3</sub>

R<sub>i</sub> (V

R<sub>2</sub>) u N M

R<sub>5</sub> R<sub>4</sub>

where R<sub>1</sub>...group -OCH<sub>2</sub>CH(OH)CH<sub>2</sub>-. The groups -OCrH<sub>2</sub>r- and -OCsH<sub>2</sub>s- are preferably oxyethylene groups.

Especially advantages **friction** reducing effects have been shown by N-(2-hydroxyalkyl)sarcosinates where the alkyl group is saturated or unsaturated, branched or unbranched and contains 16-20 carbon atoms,

The **friction**-reducing effect of the **surfactants** according to the invention is affected of both the temperature and the pH value of the solution. The temperature effect depends on whether the **surfactant** contains glycol ether groups, or not. If no such groups are present, the **surfactant** will be more hydrophilic with increasing temperature. The presence of glycol ether groups will affect the **surfactant** to be more hydrophobic when the temperature is increasing. The relative amount of the glycol...

...the ionic groups i.e. the amino and

carboxylic groups will thus determine whether the **surfactant** will be more hydrophilic or hydrophobic when the temperature is changed.

The balance between the hydrophilic and hydrophobic parts of the **surfactant** is important for its function as a **friction** reducing additive. By using a proper balance between the number of ionic groups and **nonionic** groups it is possible to design amphoteric **surfactants** with a small temperature dependence which then can be used as **friction** reducing agents within a wide temperature range,

The hydrophilicity of the amphoteric **surfactants** according to this invention is also affected by the pH-value of the water-base...

...the pH will increase the hydrophilicity of the ionic groups and due to that the **friction**-reducing properties

of the amphoteric **surfactant** are affected, This is of importance because the amphoteric **surfactant** can be adjusted to give optimal performance within a certain temperature range by an addition of an acid or a base, Also contaminations with an influence on the **surfactants micellar** shape, such as hydrocarbons or higher alcohols, may be compensated for... by an adjustment of the pH-value,

The aqueous **heat transfer** system contains at least 50 preferably at least 90 % by weight of water, Apart from the amphoteric **surfactant** it may also contain a number of conventional components such as corrosion-preventing agent, anti...8 mm and the other having an inner diameter of 10 mm. Water was **pumped** through the tube loop by a centrifugal **pump**, which was driven by a frequency-controlled motor, for continuous adjustment of the flow rate...

...rotameter,

The straight parts of the tube loop had outlets which, with the aid of **valves**, could in turn be connected to a differential pressure gauge whose other side was all...

...tube loop. Further, the tube loop was heat-insulated, and the suction side of the **pump** was connected to a thermostatically controlled container with a volume of 20 l, to which...

...for each flow rate. The pressure differences thus measured were then converted into Moody's **friction** factor  $\lambda$  and are shown in the Table below as a function of the Reynold...Table also states the corresponding Prandtl number and Virk number, The former corresponds to the **friction** factor of water only, i.e. with **turbulence**, and the latter corresponds to flow without **turbulence**,

In the tests performed one of the following compounds was added as a **friction** -reducing agent,

A. Cetyl trimethyl ammonium salicylate (comparison compound)

B, N-(2-hydroxy-cetyl)sarcosinate...

...C16 alkyl iminodipropionate

Table 1

Compound A, addition 1000 ppm, temperature 500C

3

Moody's **friction** factor  $\times 10$

Reynold's number  $\times 10^{-4}$  1 2 4 6 8

Prandtl...

...Table 2

Compound B, addition 500 ppm, temperature 660C, pH-value 8,5

Moody's **friction** factor  $\times 10^3$

Reynold's number  $\times 10^{-4}$  1 2 4 6 8

Prandtl...

...Table 3

Compound B, addition 500 ppm, temperature 980C, pH value 8,2

Moody's **friction** factor  $\times 10^3$

Reynold's number  $\times 0,8$  1,5 2,3  $3 \times 10^4$ ...

...Table 4

Compound C, addition 2000 ppm, temperature 350C, pH value 7,4

Moody's **friction** factor  $\times 10^3$

4

Reynold's number x 10<sup>-4</sup> 0,4 0,6 0's...

...2

Table 5

Compound B, addition 1000 ppm, temperature 600C, pH 9\*0

Moody's **friction** factor x 10<sup>3</sup>

Reynold's number 1\*10<sup>5</sup> 1,4 1,7 1\*9...

...6

Table 6

Compound E, addition 400 ppm, temperature 950C, pH 9,0

Moody's **friction** factor x 10<sup>3</sup>

Reynolds number x 10<sup>5</sup> 1,5 1,8 2,2 2,5 ...6 1 5, Lj

Table 7

Compound A, addition 400 ppm, temperature 700C

Moody's **friction** factor x 10<sup>3</sup>

4

Reynold's number x 10<sup>5</sup> 1,9 2,5 3,4...

...A

Table 8

Compound F, addition 1000 ppm, temperature 510C, pH 5,4

Moody's **friction** factor x 10<sup>3</sup>

Reynold's number 0,83 1,03 1,24 1,45 1...

...12 11 10 9 8 8 7

From the results it is evident that the **friction** reducing agent in accordance with the invention essentially reduces the **friction**. In many cases the **friction** is reduced-down towards the theoretical **friction** level of laminar flow (the Virk line).

The improvements in comparison with the prior art...

...the Tables 2, 31 5

and 6 it is shown that according to the invention **friction** reducing agents have an excellent effect in the temperature interval from 60 to 98'C, while the comparison compound A has no or only a very low **friction** reducing effect at 700C (Table 7),

#### Claim

Use of a water soluble amphoteric **surfactant** containing one or more, preferably one or two, monovalent hydrophobic groups forming a hydrophobic portion...

...amine groups; and one or more, preferably one or two, carboxylic groups; and having a **molecular** weight of less than 1400, or a salt thereof, as a **friction** reducing agent in a water-base liquid system,

2 Use in accordance with claim 1, characterized in that the amphoteric **surfactant** has a **molecular** weight of less than 800 and contains one or two hydrocarbon groups containing together 12...

...atoms.

3 Use in accordance with claim 1 or 2, characterized in that the amphoteric **surfactant** contains one or more **nonionic**, hydrophilic group,



4 Use in accordance with claim 1. 2 or 3, characterized in that the amphoteric **surfactant** has the formula

Ooelo@ R3

R, (N-R2) u N M

R5 R4

where R...

...3, preferably 0-1,

5 Use in accordance with claim 4, characterized in that the **surfactant** has the formula

/R3

RjN

(III)

R4

where one or two of R, I R3...Use in accordance with any one of the proceeding claims, characterized in that the amphoteric **surfactant** is used in an amount of 100-10 000 g/m3 of the water-base...

...one of the proceeding claims,

characterized in that the water-base liquid system is an **heat transfer** system,

9\* Use in accordance with claim 8, characterized in that the temperature in the...

24/3,K/11 (Item 11 from file: 348)  
DIALOG(R) File 348:EUROPEAN PATENTS  
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00190920

Use of a visco elastic surfactant composition for controlling the overall heat transfer coefficient of a heat exchange fluid.

Anwendung einer viskoelastischen oberflächenaktiven Mischung zur Steuerung des Gesamtwärmeübertragungskoeffizienten einer Wärmeaustauschflüssigkeit.

Emploi d'une composition d'un surfactant viscoelastique pour reguler le coefficient de transfert thermique total d'un fluide d'echange de chaleur.

PATENT ASSIGNEE:

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SPEC B	(English)	EPBBF1	4615
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Total word count - documents A + B			5610

Emploi d'une composition d'un surfactant viscoelastique pour reguler le coefficient de transfert thermique total d'un fluide d'echange de...

INTERNATIONAL PATENT CLASS: C09K-005/00

...SPECIFICATION system or to reduce the amount of energy employed in continuously circulating fluids in heat transfer applications. It is disclosed that polymeric materials can be added to fluids in order to reduce the amount of circulation energy. See, for example, Cho and Hartnett, Advances in Heat Transfer, 15, pg. 59 (1981).

Unfortunately, such polymeric drag reduction additives significantly reduce the heat transfer coefficient of the aqueous fluids which are employed. In addition, polymeric drag reduction additives are mechanically degraded due to the shearing action of pumps, and the like.

WO 83/01583 teaches a method for reducing friction exhibited by a liquid passing through a conduit by using a viscoelastic surfactant composition.

EP-B1 0 091 086 discloses the addition of a small amount of certain surfactants to reduce the drag of aqueous media in turbulent or

pulsating flow.

This invention is directed to the use of a viscoelastic **surfactant** composition comprising (1) a **surfactant** compound having a hydrophobic moiety chemically bonded to an ionic hydrophilic moiety and an electrolyte having a moiety that is capable of associating with the **surfactant** ion to form a viscoelastic **surfactant**, said **surfactant** compound represented by the formula:

(Chemical formula omitted)

wherein the hydrophobic moiety  $R_{(sub\ 1)}$ ...

...length of at least 12 carbon atoms or alkenyl and is chemically bonded to a **cationic** moiety  $Y^{(sup\ +)}$  or **anionic** moiety  $Z^{-}$  with **counterions**  $X^{-}$  and  $A^{(sup\ +)}$ , respectively; or (2) a **surfactant** compound having a hydrophobic moiety chemically bonded to a **nonionic** hydrophilic moiety, said **surfactant** compound represented by the formula:

(Chemical formula omitted)

wherein  $R_{(sub\ 1)}$  is as previously defined and is chemically bonded to a **nonionic** moiety  $N$ , as an additive for controlling the overall **heat transfer** coefficient of a **heat exchange** fluid in such a manner that the **heat transfer** coefficient is similar to that of the **heat exchange** fluid not containing the **surfactant** composition at or above a critical temperature or critical mass flow rate thereby providing a high **heat transfer** coefficient in a high temperature **heat exchange** region while providing **drag** reduction and a low **heat transfer** coefficient in the distribution lines.

Optionally, a further amount of an electrolyte having a moiety that is capable of associating with the **surfactant** ion is incorporated in the viscoelastic **surfactant** composition. For purposes of this invention, a viscoelastic **surfactant** is a compound having (1) an ion capable of acting as a **surfactant** and (2) a stoichiometric amount of a **counterion** that associates with the **surfactant** ion to render it viscoelastic as defined hereinafter. The further amount of electrolyte can be the same or different from that **counterion** associated with the **surfactant** ion. The resulting viscoelastic **surfactant** is employed in an amount sufficient to reduce the amount of **friction** experienced by the **heat transfer** fluid in the **heat transfer** apparatus. The fluids employed in this invention are highly **shear** stable and do not experience any loss of **friction** reduction activity with continued pumping, as compared to polymeric **drag** reduction additives which undergo irreversible mechanical **degradation** and rapid loss of **friction** reduction activity with continued pumping.

Surprisingly, the presence of the additional electrolyte in an aqueous liquid containing the viscoelastic **surfactant** in accordance with the practice of this invention significantly further reduces the **friction** both over velocities and temperatures experienced by the fluid containing the viscoelastic **surfactant** as the...

...is employed in heat transfer applications. The admixture of the aqueous liquid, electrolyte and viscoelastic **surfactant** is significantly more **shear** stable than an aqueous liquid containing a polymer capable of providing the aqueous liquid with the same degree of **friction** reduction.

The invention is useful in those processes where fluids are employed in general lubricating and **heat transfer** applications such as various closed-loop recirculating systems. Of particular interest are district

heating applications and **hydronic** heating, cooling applications, and the like.

As used herein, the term "fluid" refers to those fluid materials which can be employed in **heat transfer** applications. **Heat transfer** fluids can be organic or aqueous in nature. Most preferably, the fluid is an aqueous...

...aqueous solutions of inorganic salts, aqueous alkaline or aqueous acidic solutions, depending upon the particular **surfactant** and electrolyte employed, e.g., an aqueous solution of an alkali metal or alkaline earth ...i.e., the liquid at least partially returns to its original form when an applied **stress** is released. The property of viscoelasticity is well-known in the art and reference is...

...found to be most useful in determining the viscoelasticity of an aqueous solution consists of **swirling** the solution and visually observing whether the bubbles created by the **swirling** recoil after the **swirling** is stopped. Any recoil of the bubbles indicates viscoelasticity.

The ionic **surfactant** compounds comprise an ionic hydrophobic **molecule** having an ionic, hydrophilic moiety chemically bonded to a hydrophobic moiety (herein called a **surfactant** ion) and a **counterion** sufficient to satisfy the charge of the **surfactant** ion and are represented by the formula:

(Chemical formula omitted)

wherein  $R(\text{sub } 1)(Y(\text{sup } ))$  and  $R(\text{sub } 1)(Z(\text{sup } ))$  represent **surfactant** ions having a hydrophobic moiety represented by  $R(\text{sub } 1)$  and an ionic, solubilizing moiety represented by the **cationic** moiety  $(Y(\text{sup } ))$  or the **anionic** moiety  $(Z(\text{sup } ))$  chemically bonded thereto.  $X(\text{sup } )$  and  $A(\text{sup } )$  are the **counterions** associated with the **surfactant** ions.

The hydrophobic moiety (i.e.,  $R(\text{sub } 1)$ ) of the **surfactant** ion is hydrocarbyl or inertly substituted hydrocarbyl wherein the term "inertly substituted" refers to hydrocarbyl...

...to 24 carbon atoms, with octadecyl, hexadecyl, erucyl and tetradecyl being the most preferred.

The **cationic**, hydrophilic moieties (groups), i.e.,  $(Y(\text{sup } ))$ , are generally onium ions wherein the term "onium ions" refers to a **cationic** group which is essentially completely ionized in water over a wide range of pH, e...

...moieties will exist in ionic form. A pyridinium moiety can also be employed. Of such **cationic** groups, the **surfactant** ion of the viscoelastic **surfactant** is preferably prepared having quaternary ammonium, i.e.,  $-N(\text{sup } )(R(\text{sub } 3))$ ; a pyridinium...

...1 to 4 carbon atoms, with each R preferably being methyl, ethyl or hydroxyethyl.

Representative **anionic**, solubilizing moieties (groups)  $(Z(\text{sup } ))$  include sulfate groups, i.e.,  $-OSO(\text{sub } 3)(\text{sup } )$ , ether...

... $SO(\text{sub } 3)(\text{sup } )$ , carboxylate groups, phosphate groups, phosphonate groups, and phosphonite groups. Of such **anionic** groups, the **surfactant** ion of the viscoelastic **surfactants** is preferably prepared having a carboxylate or sulfate group. For purposes of this invention, such **anionic** solubilizing moieties are less preferred than **cationic** moieties.

The **counterions** (i.e.,  $X(\text{sup } )$  or  $A(\text{sup } )$ ) associated with the

**surfactant** ions are most suitably ionically charged, organic materials having ionic character opposite that of the **surfactant** ion, which combination of **counterion** and **surfactant** ion imparts viscoelastic properties to an aqueous liquid. The organic material having an **anionic** character serves as the **counterion** for a **surfactant** ion having a **cationic**, hydrophilic moiety, and the organic material having a **cationic** character serves as the **counterion** for the **surfactant** ion having an **anionic**, hydrophilic moiety. In general, the preferred **counterions** exhibiting an **anionic** character contain a carboxylate, sulfonate or phenoxide group wherein a "phenoxide group" is  $\text{ArO}(\text{sup})$  and Ar represents an aromatic ring or inertly substituted aromatic ring. Representative of such **anionic counterions** which, when employed with a **cationic surfactant** ion, are capable of imparting viscoelastic properties to an aqueous liquid include various aromatic carboxylates...

...such as p-toluene sulfonate and naphthalene sulfonate; and phenoxides, particularly substituted phenoxides; where such **counterions** are soluble; or 4-amino-3,5,6-trichloropicolinate. Alternatively, the **cationic counterions** can contain an onium ion, most preferably a quaternary ammonium group. Representative **cationic counterions** containing a quaternary ammonium group include benzyl trimethyl ammonium or alkyl trimethyl ammonium wherein the It is highly desirable to avoid stoichiometric amounts of **surfactant** and **counterion** when the alkyl group of the **counterion** is large. The use of a **cation** as the **counterion** is generally less preferred than the use of an **anion** as the **counterion**. Inorganic **counterions**, whether **anionic** or **cationic**, can also be employed.

The particular **surfactant** ion and the **counterion** associated therewith are selected such that the combination imparts viscoelastic properties to an aqueous liquid. Of the aforementioned **surfactant** ions and **counterions**, those combinations which form such viscoelastic **surfactants** will vary and are easily determined by the test methods hereinbefore described. Of the **surfactants** which impart viscoelastic properties to an aqueous liquid, the preferred **surfactant** compounds include those represented by the formula: (see image in original document) wherein n is...

...to 4 carbon atoms. In addition, each R can form a pyridinium moiety. Especially preferred **surfactant** ions include cetyltrimethylammonium, oleyltrimethylammonium, erucyltrimethylammonium and cetylpyridinium.

The viscoelastic **surfactants** are easily prepared by admixing the basic form of the desired **cationic surfactant** ion (or acidic form of the desired **anionic surfactant** ion) with a stoichiometric amount of the acidic form of the desired **cationic counterion** (or basic form of the desired **anionic counterion**). Alternatively, stoichiometric amounts of the salts of the **cationic surfactant** ion and the **anionic counterion** (or equimolar amounts of the **anionic surfactant** ion and **cationic counterion**) can be admixed to form the viscoelastic **surfactant**. See, for example, the procedures described in U.S. Patent 2,541,816.

The viscoelastic **surfactant** (whether ionic or **nonionic** in character) is employed in an amount sufficient to impart viscoelastic properties to the fluid...

...the fluid is measured by the techniques described herein. In general, such amount of viscoelastic **surfactant** is sufficient to measurably reduce the **friction** exhibited by the fluid as it is employed in heat **transfer** applications. The specific viscoelastic **surfactant** employed

and the concentration thereof in the fluid are dependent on a variety of factors including solution composition, temperature, and **shear** rate to which the flowing fluid will be subjected. In general, the concentration of any specific viscoelastic **surfactant** most advantageously employed herein is easily determined by experimentation. In general, the viscoelastic **surfactants** are preferably employed in amounts ranging from 0.01 to 10 weight percent based on the weight of the **surfactant** and fluid. The viscoelastic **surfactant** is more preferably employed in amounts from 0.05 to 1 percent based on the weight of the fluid and the viscoelastic **surfactant**.

In one highly preferred aspect of the practice of this invention, an electrolyte having an ionic character opposite to that of the **surfactant** ion and capable of being associated as an organic **counterion** with said **surfactant** ion is employed in an additional amount to further reduce the **friction** exhibited by the fluid containing the viscoelastic **surfactant** and to increase the temperature to which the fluid will maintain **drag** reduction. Such electrolytes most suitably employed herein include those containing organic ions which, when associated with the **surfactant** ions of the **surfactant** compound, form a viscoelastic **surfactant**. The organic electrolyte, when present in an excess of that which stoichiometrically associates with the **surfactant** ion, is capable of further reducing **friction** of the fluid and to increase the temperature to which the fluid will maintain **drag** reduction. Such organic electrolyte is soluble in the fluid containing the viscoelastic **surfactant**.

The concentration of the organic electrolyte required in the fluid to impart the further reduction in **friction** and increase the temperature to which the fluid will maintain **drag** reduction is dependent on a variety of factors including the particular fluid, viscoelastic **surfactant** and organic electrolyte employed, and the achieved reduction in **drag**. In general, the concentration of the organic electrolyte will advantageously range from 0.1 to 20, preferably from 0.5 to 5, moles per mole of the viscoelastic **surfactant**.

In general, the organic ions are formed by the dissociation of corresponding organic electrolytes, including...

...of a suitable organic ion. For example, an organic electrolyte which, upon dissociation, forms an **anion** will further reduce the **friction** of a fluid containing a viscoelastic **surfactant** having a **cationic surfactant** ion. Examples of such **anionic** organic electrolytes include the alkali metal salts of various aromatic carboxylates such as the alkali...

...g., ar,ar-dichlorophenols, 2,4,5-trichlorophenol, t-butylphenol, t-butylhydroxyphenol, and ethylphenol.

A **cationic** organic electrolyte which, upon dissociation, forms a **cation** is also useful in further reducing the **friction** of a fluid containing a viscoelastic **surfactant** having an **anionic surfactant** ion. While **cationic** organic electrolytes are less preferred than the aforementioned **anionic** organic electrolytes, examples of suitable **cationic** electrolytes include the quaternary ammonium salts such as alkyl trimethylammonium halides and alkyl triethylammonium halides...

...halides. Also desirable is cyclohexyl amine. It is highly desirable to avoid stoichiometric amounts of **surfactant** and **counterion** when the alkyl group of the **counterion** is large (i.e., greater than 8).

Preferably, the organic electrolyte is the same or generates the same ion associated with the **surfactant** ion of the viscoelastic **surfactant** contained ...g., alkali metal salicylate is advantageously employed as

the additional organic electrolyte when the viscoelastic **surfactant** is originally prepared having a salicylate or p-toluene sulfonate **counterion**. Therefore, the most preferred organic electrolytes are the alkali metal salts of an aromatic carboxylate...

...toluene sulfonate. Moreover, it is also understood that the electrolyte can be different from the **counterion** which is employed.

It is also possible to employ a water-insoluble active ingredient such

...  
...organic ingredient emulsified in water at a concentration of 0.05 to 80 percent. Viscoelastic **surfactants** (whether ionic or **nonionic** in character) employed in such emulsions tend to lose their viscoelasticity. This is believed to be due to the fact that the oil penetrates the **micelles** and destroys the aggregates required for viscoelasticity. Viscoelastic **surfactants** containing excess organic electrolyte are capable of withstanding the addition of oil to aqueous liquids for longer periods of time than those viscoelastic **surfactants** without the excess organic electrolyte. However, fluorinated viscoelastic **surfactants** are able to withstand the addition of oil to the aqueous liquid in amounts up  
...

...to 20 weight percent for a longer period of time.

The fluids which exhibit reduced **friction** when used in industrial **heat transfer** applications are prepared by admixing the desired amounts of the viscoelastic **surfactant** and organic electrolyte to form a fluid solution. Alternatively, the **nonionic surfactant** is contacted with the fluid to form an aqueous liquid solution. The resulting solutions are...

...can be employed for numerous industrial purposes. Examples of industrial uses include district heating or **hydronic** heating in buildings.

The fluids employed in the process of this invention can exhibit **heat transfer** coefficients over a flow rate/temperature range which are lower than fluids not containing the viscoelastic additives. However, the fluids employed in this invention exhibit **heat transfer** coefficients similar to that of a fluid not containing the viscoelastic additives at or above...

...critical temperature or critical mass flow rate. Thus, it is possible to provide a high **heat transfer** coefficient in a high temperature **heat exchange** region, while providing **drag** reduction and a low **heat transfer** coefficient in the distribution lines.

The critical temperature and critical mass flow rate can depend on the **surfactant** ion structure and the **counterion** concentration of the viscoelastic **surfactant**. For example, longer alkyl chain length **surfactant** ions and/or an excess of **counterion** can be employed to provide a fluid having a higher critical temperature and critical mass flow rate than in comparable fluid formulations. Thus, it is possible to design **heat transfer** fluids which can be designed to match the particular flow rate requirements and temperature of a wide variety of **heat transfer** applications.

The fluids employed in the process of this invention can be employed under conditions in which previously known **heat transfer** fluids have been employed. Preferred applications include those processes where **heat exchange** apparatus is operated between -40(degree)C and 150(degree)C. For example, compositions can...

...in order to match the temperature conditions and flow rate requirements in order to achieve **heat transfer** in a hot exchanger in a heating plant. However, the compositions have the desired **drag** reduction and

lower **heat transfer** coefficient in the cooler distribution lines.

The following examples are presented to illustrate the invention. All percentages and parts are by weight unless otherwise noted.

In order to determine the **friction** exhibited under flow conditions and the **heat transfer** properties of aqueous compositions, a pipe flow test loop is prepared. The test loop comprises a pumping system, a heating and cooling system and a testing system.

A centrifugal **pump** is responsible for pumping the fluid around the loop. Its maximum output is approximately 150...

...is around 75 psi (517 kPa) gage. The rest of the loop consists of a **heat exchanger**, a mass flow meter, a test section, and a 20-gal. (0.076 m(sup 3))

...in diameter, all the lines are 2 inches (51 mm) in diameter. All of the **valves** in this loop are ball **valves** except for three butterfly **valves** in the 3 inch (76 mm) lines around the 20-gal. (0.076 m(sup 3)) tank. The centrifugal **pump** is capable of handling slurries and the loop itself is built with long radius bends...

...30 gallons or 0.1 m(sup 3)).

In order to prevent cavitation in the **pump** during start-up and air entrapment, a 2 inch (51 mm) diameter 3 feet (0...

...tank. Once the system is filled there are no air legs in the lines. The **valve** on the bypass is closed half way when running to divide the flow between the...

...400 lb. steam regulated to 100 psi (689 kPa) gage and tap water using two **heat exchangers**. The first **heat exchanger** heats or cools an intermediate **heat transfer** fluid with the steam or tap water. The intermediate **heat transfer** fluid is **pumped** to the second main **heat exchanger** which heats or cools the test fluid. The intermediate **heat transfer** fluid is water containing a corrosion inhibitor. Temperature probes are placed at the inlets and outlets of the main **heat exchanger** to gather **heat transfer** data. A solenoid **valve** is placed in the water/steam drain line in order to increase the pressure and...

...pressure taps drilled 45 cm apart near the center of the pipe. They do not **disturb** the flow field in the pipe. The entrance length from the last **disturbance** before the pressure taps (the flow control **valve**) exceeds 50 times the diameter of the pipe in order that the taps should be...

...though 7

Example 1 is an aqueous composition containing 0.2 percent of a viscoelastic **surfactant** of cetyltrimethylammonium salicylate prepared by admixing equimolar amounts of cetyltrimethylammonium chloride and sodium salicylate.

Example...

...are initially at 40(degree)C, 50(degree)C and 60(degree)C. The intermediate **heat transfer** fluid is at 70(degree)C. The temperatures of the intermediate **heat transfer** fluid entering and leaving the annulus of the main **heat exchanger** and the temperature of the test fluid entering and leaving the main **heat exchangers** are measured at the different mass flow rates. The overall **heat transfer** coefficient of the test fluids is calculated using the equations:

(Chemical formula omitted)



wherein:

$Q$  = heat transferred in BTU to the test fluid  
 $m$  = mass flow rate in lb/(hr ft<sup>sup 2</sup>...

...lb (degree)F  
(DELTA)t = temperature rise of the test fluid passing through the main heat exchanger ( $t(\text{sub } 2) - t(\text{sub } 1)$ ), in (degree)F  
 $U$  = overall heat transfer coefficient in BTU/(lb (degree)F ft<sup>(sup 2)</sup>) W/(m<sup>(sup 2)</sup>) K  
 $A$  = is area of heat exchanger in ft<sup>(sup 2)</sup>  
(DELTA) $T(\text{sub } 1m)$  = logarithmic mean temperature drop in (degree)F (see image in original document)  
 $T(\text{sub } 1)/T(\text{sub } 2)$  = temperature of the intermediate heat transfer fluid entering/leaving the annulus of the main heat exchanger in (degree)F  
 $t(\text{sub } 1)/t(\text{sub } 2)$  = temperature of the test fluid entering/leaving the main heat exchanger .

Data concerning the effect of the temperature and the mass flow rate on the overall heat transfer coefficient  $U$  is presented in Table I. (see image in original document)

The data in...

...coefficient  $U$  of the fluid containing the viscoelastic surfactant returns to that of water.

The heat transfer data in Table I follows the same trend with increasing temperatures or mass flow rate as pipe flow friction reduction data. As the temperature is increased or the mass flow rate is increased, a...

...of the solvent (in this case water). The critical temperatures and critical flow rates for drag reduction are somewhat higher for pipe flow friction data than they are for the heat transfer data. Since the trends are the same, the pipe flow friction critical temperatures and critical flow rates can be used to predict the performance of the overall heat transfer coefficient.

Example 3 is an aqueous composition containing 0.2 percent cetyltrimethylammonium salicylate and 0...

...aqueous composition containing 0.2 percent erucyltrimethylammonium salicylate and 0.2 percent sodium salicylate.

Fanning Friction Factors for Examples 1, 3, 4, 5, 6 and 7 are calculated for each composition...

...temperatures and at Reynolds Numbers between 60,000 and 965,000 using the equation: Fanning Friction Factor (see image in original document) wherein:

$D$  = diameter in cm of the circular conduit...

...the liquid flows

$V$  = velocity in cm/sec of the aqueous liquid The minimum Fanning Friction Factors for each temperature are reported in Table II. (see image in original document)

The data in Table II illustrate that the surfactant ion and excess counterion can raise the critical temperature at which the minimum Fanning Friction Factor is observed.

The data in Tables I and II illustrate that the critical temperature and critical mass flow rate depend on both the surfactant ion structure and counterion concentration in the test fluid. Thus, viscoelastic surfactant formulations can be designed in order to match the temperature conditions and flow rate requirements in a wide variety of heat transfer applications. ...

24/3,K/12 (Item 12 from file: 349)  
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00124830

**A METHOD FOR CONTROLLING THE OVERALL HEAT TRANSFER COEFFICIENT OF A HEAT EXCHANGE FLUID**

**PROCEDE DE REGULATION DU COEFFICIENT DE TRANSFERT THERMIQUE TOTAL D'UN FLUIDE D'ECHANGE DE CHALEUR**

Patent Applicant/Assignee:

THE DOW CHEMICAL COMPANY,

Inventor(s):

ROSE Gene D,

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Detailed Description

Claims

Detailed Description

... the fric

tion both over velocities and temperatures experienced by the fluid containing the viscoelastic **surfactant** as the liquid is employed in heat transfer applications. The admixture of the aqueous liquid, electrolyte and viscoelastic **surfactant** is significantly more **shear** stable than an aqueous liquid containing a polymer capable of providing the aqueous liquid with the same degree of **friction** reduction

In another aspect, the present invention is a method for imparting **shear** stable **heat transfer** properties to fluids through the use of a **nonionic** viscoelastic **surfactant**. This method comprises contacting said aqueous liquid with a functionally effective amount of a **surfactant** compound having a hydrophobic moiety chemically bonded to a **nonionic**, hydrophilic moiety (hereinafter a **nonionic surfactant**), which compound is capable of exhibiting a viscoelastic character. The **nonionic** viscoelastic **surfactant** is employed in an amount sufficient to reduce the amount of **friction** experienced by the **heat transfer** fluid as it is employed in the **heat transfer** apparatus

The method of this invention is useful in those processes where fluids are employed in general lubricating and **heat transfer** applications such as various closed-loop recirculating systems. Of particular interest are district heating applications and **hydronic** heating, cooling applications, and the like

As used herein, the term "fluid" refers to those fluid materials which can be employed in **heat transfer** applications. **Heat transfer** fluids can be

organic or aqueous in nature. Most preferably, the fluid is an aqueous upon the particular

**surfactant** and electrolyte employed, e.g., an aqueous solution of an alkali metal or alkaline earth...i.e., the liquid at least partially returns to

its original form when an applied **stress** is released.

The property of viscoelasticity is well-known in the

art and reference ...found to be

most useful in determining the viscoelasticity of an aqueous solution consists of **swirling** the solution and visually observing whether the bubbles created by the

**swirling** recoil after the **swirling** is stopped. Any recoil of the bubbles indicates viscoelasticity

**Surfactant** compounds within the scope of this invention include compounds broadly classified as

**surfactants** which, through the proper choice of **counterion** structure and environment, give viscoelasticity.

The term "**surfactant** (deg) is taken to mean any **molecule**

having a characteristic amphiphatic structure such that

it has the property of forming colloidal clusters,

commonly called **micelles**, in solution

In general, ionic **surfactant** compounds comprise an ionic hydrophobic **molecule** having an ionic, hydrophilic moiety chemically bonded to a hydrophobic moiety (herein called a **surfactant** ion) and a **counterion** sufficient to satisfy the charge of the **surfactant** ion. Examples of such **surfactant** compounds are represented by the formula:

$Y(D)X_9$  or

wherein  $R_1(Y(R))$  and  $R_1(Z_9)$  represent **surfactant** ions having a hydrophobic moiety represented by  $R_1$  and an ionic, solubilizing moiety represented by the **cationic** moiety  $(Y(R))$  or the **anionic** moiety  $(Z_9)$  chemically bonded thereto.  $X_8$  and  $A(R)$  are the **counterions** associated with the **surfactant** ions

E

In general, the hydrophobic moiety (i.e.,  $R_1$ ) of the **surfactant** ion is hydrocarbyl or inertly substituted hydrocarbyl wherein the term "...to 24 carbon atoms, with octadecyl, hexadecyl, erucyl and tetradecyl being the most preferred

The **cationic**, hydrophilic moieties (groups), i.e.,  $(Y_0)$ , are generally onium ions wherein the term "onium ions" refers to a **cationic** group which is essentially completely ionized in water over a wide range of pH...moieties will exist in ionic form. A pyridinium moiety can also be employed. Of such **cationic** groups, the **surfactant** ion of the viscoelastic **surfactant** is preferably prepared having quaternary ammonium, i.e.,  $-N(R)(R)_3$ ; a pyridinium moiety...1 to 4 carbon atoms, with each  $R$  preferably being methyl, ethyl or hydroxyethyl

Representative **anionic**, solubilizing moieties (groups)  $(Z_9)$  include sulfate groups, i.e.,  $-OSO_3e$ , ether sulfate groups, sulfonate groups, i.e.,  $-SO_3G$ , carboxylate groups, phosphate groups, phosphonate

groups, and phosphonite groups. Of such **anionic** groups, the **surfactant** ion of the viscoelastic **surfactants** is preferably prepared having a carboxylate or sulfate group. For purposes of this invention, such **anionic** solubilizing moieties are less preferred than **cationic** moieties.

Fluoroaliphatic species suitably employed in the practice of this invention include organic compounds...

...Z' is an ionic moiety or potentially ionic moiety. The fluoroaliphatics can be perfluorocarbons. Suitable **anionic** and **cationic** moieties will be described hereinafter. The fluoroaliphatic moiety advantageously contains from 3 to 20 carbons...those linear perfluoroaliphatic moieties represented in the paragraphs below

The fluoroaliphatic species can be a **cationic** perfluorocarbon and is preferably selected from a member of the group consisting of CF<sub>3</sub> wherein X<sub>9</sub> is a **counterion** described hereinafter, "R" is lower alkyl containing between 1 and 4 carbon atoms, r is...

...15, preferably 2 to 6, and s is 2 to 5. Examples of other preferred **cationic** perfluorocarbons, as well as methods of preparation, are those listed in U.S.

Patent No. 3,775,126

The fluoroaliphatic species can be an **anionic** perfluorocarbon and is preferably selected from a member of the group consisting of CF<sub>3</sub>(CF<sub>2</sub>...

...preferably 2 to 6, q is from 2 to 4, and A(R) is a **counterion** described hereinafter. Examples of other preferred **anionic** perfluorocarbons, as well as methods of preparation, are illustrated in U.S. Patent No

3,172,910

The **counterions** (i.e., X<sub>9</sub> or A<sub>5</sub>) associated with the **surfactant** ions are most suitably ionically charged, organic materials having ionic character opposite that of the **surfactant** ion, which combination of **counterion** and **surfactant** ion imparts viscoelastic properties to an aqueous liquid. The organic material having an **anionic** character serves as the **counterion** for a **surfactant** ion having a **cationic**, hydrophilic moiety, and the organic material having a **cationic** character serves as the **counterion** for the **surfactant** ion having an **anionic**, hydrophilic moiety. In general, the preferred **counterions** exhibiting an **anionic** character contain a carboxylate, sulfonate or phenoxide group wherein a "phenoxide group" is ArO<sub>9</sub> and Ar represents an aromatic ring or inertly substituted aromatic ring. Representative of such **anionic counterions** which, when employed with a **cationic surfactant** ion, are capable of

-10

imparting viscoelastic properties to an aqueous liquid include various aromatic where such **counterions** are soluble; or 4-amino-3,5,6-trichloropicolinate. Alternatively, the **cationic counterions** can contain an onium ion, most preferably a quaternary ammonium group. Representative **cationic counterions** containing a quaternary ammonium group include benzyl trimethyl ammonium or alkyl trimethyl ammonium wherein the...

...and amines such as cyclohexyl amine. It is highly desirable to avoid stoichiometric amounts of **surfactant** and **counterion** when the alkyl group of the **counterion** is large. The use of a **cation** as the **counterion** is generally less preferred than the use of an **anion** as the **counterion**. Inorganic **counterions**, whether **anionic** or **cationic**, can also be employed

The particular **surfactant** ion and the **counterion** associated therewith are selected such that the combination imparts viscoelastic properties to an aqueous liquid. Of the aforementioned **surfactant** ions and **counterions**, those combinations which form such viscoelastic **surfactants** will vary and are easily determined by the test methods hereinbefore described. Of the **surfactants** which impart viscoelastic properties to an aqueous liquid, the preferred **surfactant** compounds include those represented by the formula:

$\text{CH}_3 + \text{CH}_2\text{N}(\text{R})\text{R} \text{X}_8$  R1  
R...to 4 carbon atoms. In addition, each R can form a pyridinium moiety

Especially preferred **surfactant** ions include cetyltrimethylammonium, oleyltrimethylammonium, erucyltrimethylammonium and cetylpyridinium

Other preferred **surfactant** compounds include those represented by the formula:

$\text{CF}_3 - (\text{CF}_2)_n - \text{SO}_2\text{NH} - (\text{CH}_2)_m - \text{N} - \text{R}$

previously defined, most preferably methyl; and X9 is as previously defined

...is as

The viscoelastic **surfactants** are easily prepared by admixing the basic form of the desired **cationic surfactant** ion (or acidic form of the desired **anionic surfactant** ion) with a stoichiometric amount of the acidic form of the desired **cationic counterion** (or basic form of the desired **anionic counterion**). Alternatively, stoichiometric amounts of the salts of the **cationic surfactant** ion and the **anionic counterion** (or equimolar amounts of the **anionic surfactant** ion and **cationic counterion**) can be admixed to form the viscoelastic **surfactant**. See, for example, the procedures described in U.S. Patent 2,541,816

In general, **surfactant** compounds having a hydrophobic moiety chemically bonded to a **nonionic**, hydrophilic moiety are those **nonionic surfactants** which exhibit a viscoelastic character, and are typically described in U.S. Patent No. 3,373,107; and those alkylphenyl ethoxylates as are described by Shinoda in

Solvent Properties of **Surfactant** Solutions, Marcel Dekker, Inc. (1967). Preferred **nonionic surfactants** are those tertiary amine oxide **surfactants** which exhibit viscoelastic character. In general, the hydrophobic moiety can be represented as the previously described R1. It is understood that the **nonionic surfactant** can be employed in the process of this invention in combination with an additional...

...to employ an additive such as an alkanol in the aqueous liquid to which the **nonionic surfactant** is added in order to render the **surfactant** viscoelastic

Other viscoelastic **surfactants** which can be employed in the process of this invention are described by D. Saul...al., J. Chem. Soc, Faraday Trans., 1 (1974) 70(1), pp. 163-170

The viscoelastic **surfactant** (whether ionic or **nonionic** in character) is employed in an amount sufficient to impart viscoelastic properties to the fluid...

...the fluid is measured by the techniques described herein. In general, such amount of viscoelastic **surfactant** is sufficient to measurably reduce the **friction** exhibited by the fluid as it is employed in heat **transfer** applications. The specific viscoelastic **surfactant** employed and the concentration thereof in the fluid are dependent on a variety of factors including solution composition, temperature, and **shear** rate ...which the flowing fluid will be subjected. In general, the concentration of any specific viscoelastic **surfactant** most advantageously employed herein is easily determined by experimentation. In general, the viscoelastic **surfactants** are preferably employed in amounts ranging from 0.01 to 10 weight percent based on the weight of the **surfactant** and fluid. The viscoelastic **surfactant** is more preferably employed in amounts from 0.05 to 1 percent based on the weight of the fluid and the viscoelastic **surfactant**

In one highly preferred aspect of the practice of this invention, an electrolyte having an ionic character opposite to that of the **surfactant** ion and capable of being associated as an organic **counterion** with said **surfactant** ion is employed in an additional amount to further reduce the **friction** exhibited by the fluid containing the viscoelastic **surfactant** and to increase the temperature to which the fluid will maintain **drag** reduction. Such electrolytes most suitably employed herein include those containing organic ions which, when associated with the **surfactant** ions of the **surfactant** compound, form a viscoelastic **surfactant**. The organic electrolyte, when present in an excess of that which stoichiometrically associates with the **surfactant** ion, is capable of further reducing **friction** of the fluid and to increase the temperature to which the fluid will maintain **drag** reduction. Such organic electrolyte is soluble in the fluid containing the viscoelastic

## surfactant

The concentration of the organic electrolyte required in the fluid to impart the further reduction in **friction** and increase the temperature to which the fluid will maintain **drag** reduction is dependent on a variety of factors including the particular fluid, viscoelastic **surfactant** and organic electrolyte employed, and the achieved reduction in **drag**. In general, the concentration of the organic electrolyte will advantageously range from 0.1 to 20, preferably from 0.5 to 5, moles per mole of the viscoelastic **surfactant**.

In general, the organic ions are formed by the dissociation of corresponding organic electrolytes, including...

...of a suitable organic ion. For example, an organic electrolyte which, upon dissociation, forms an **anion** will further reduce the **friction** of a fluid containing a viscoelastic **surfactant** having a **cationic surfactant** ion. Examples of such **anionic** organic electrolytes include the alkali metal salts of various aromatic carboxylates such as the alkali...ar, ar-dichlorophenols, 2,4,5-trichlorophenol, t-butyl phenol, t-butylhydroxyphenol, and ethylphenol.

A **cationic** organic electrolyte which, upon dissociation, forms a **cation** is also useful in further reducing the **friction** of a fluid containing a viscoelastic **surfactant** having an **anionic surfactant** ion. While **cationic** organic electrolytes are less preferred than the aforementioned **anionic** organic electrolytes, examples of suitable **cationic** electrolytes include the quaternary ammonium salts such as alkyl trimethyl ammonium halides and alkyl triethylammonium...

...halides. Also desirable is cyclohexyl amine. It is highly desirable to avoid stoichiometric amounts of **surfactant** and **counterion** when the alkyl group of the **counterion** is large (i.e., greater than 8).

Preferably, the organic electrolyte is the same or generates the same ion associated with the **surfactant** ion of the viscoelastic **surfactant** contained by the aqueous liquid, e.g., alkali metal salicylate is advantageously employed as the additional organic electrolyte when the viscoelastic **surfactant** is originally prepared having a salicylate or p-toluene sulfonate **counterion**. Therefore, the most preferred organic electrolytes are the alkali metal salts of an aromatic carboxylate...

...toluene sulfonate. Moreover, it is also understood that the electrolyte can be different from the **counterion** which is employed.

It is also possible to employ a water-insoluble active ingredient such ingredient emulsified in water at a concentration of

0.05 to 80 percent. Viscoelastic **surfactants** (whether ionic or **nonionic** in character) employed in such emulsions tend to lose their viscoelasticity. This is believed to be due to the fact that the oil penetrates the **micelles** and destroys the aggregates required for viscoelasticity. Viscoelastic **surfactants** containing excess organic electrolyte are capable of withstanding the addition of oil to aqueous liquids for longer periods of time than those viscoelastic **surfactants** without the excess organic electrolyte. However, fluorinated viscoelastic **surfactants** are able to withstand the addition of oil to the aqueous liquid ...up to weight percent for a longer period of time

The fluids which exhibit reduced **friction** when used in industrial **heat transfer** applications are prepared by admixing the desired amounts of the viscoelastic **surfactant** and organic electrolyte to form a fluid solution. Alternatively, the **nonionic surfactant** is contacted with the fluid to form an aqueous liquid solution. The resulting solutions are industrial uses include district heating or **hydronic** heating in buildings

The fluids employed in the process of this invention can exhibit **heat transfer** coefficients over a flow rate/temperature range which are lower than fluids not containing the viscoelastic additives. However, the fluids employed in this invention exhibit **heat transfer** coefficients similar to that of a fluid not containing the viscoelastic additives at or above...

...critical temperature or critical mass flow rate. Thus, it is possible to provide a high **heat transfer** coefficient in a high temperature **heat exchange** region, while providing **drag** reduction and a low **heat transfer** coefficient in the distribution lines. The critical temperature and critical mass flow rate can depend on the **surfactant** ion structure and the **counterion** concentration of the viscoelastic **surfactant**. For example, longer alkyl chain length **surfactant** ions and/or an excess of **counterion** can be employed to provide a fluid having a higher critical temperature and critical mass flow rate than in comparable fluid formulations. Thus, it is possible to design **heat transfer** fluids which can be designed to match the particular flow rate requirements and temperature of a wide variety of **heat transfer** applications.

The fluids employed in the process of this invention can be employed under conditions in which previously known **heat transfer** fluids have been employed. Preferred applications include those processes where **heat exchange** apparatus is operated between -40(deg)C and 150(deg)C. For example, compositions can...

...in order to match the temperature conditions and flow rate requirements in order to achieve **heat transfer** in a hot



exchanger in a heating plant. However, the compositions have the desired **drag** reduction and lower **heat transfer** coefficient in the cooler distribution lines

The following examples are presented to illustrate the invention...All percentages and parts are by weight unless otherwise noted.

In order to determine the **friction** exhibited under flow conditions and the **heat transfer** properties of aqueous compositions, a pipe flow test loop is prepared. The test loop comprises a pumping system, a heating and cooling system and a testing system

A centrifugal **pump** is responsible for pumping the fluid around the loop. Its maximum output is approximately 150 **heat exchanger**, a mass flow meter, a test section, and a 20-gal. (0.076 m<sup>3</sup>) expansion...

...in diameter, all the lines are 2 inches (51 mm) in diameter

All of the **valves** in this loop are ball **valves** except for three butterfly **valves** in the 3 inch (76 mm) lines around the 20-gal. (0.076 m<sup>3</sup>) tank. The centrifugal **pump** is capable of handling slurries and the loop itself is built with long radius bends...

...liters (about 30 gallons or 0.1 m<sup>3</sup>)

In order to prevent cavitation in the **pump** during start-up and air entrapment, a 2 inch (51 mm) diameter 3 feet (0.91 m) tank. Once the system is filled there are no air legs in the lines

The **valve** on the bypass is closed half way when running to divide the flow between the...

...400 lb. steam regulated to 100 psi (689 kPa) gage and tap water using two **heat exchangers**. The first **heat exchanger** heats or cools an intermediate **heat transfer** fluid with the steam or tap water. The intermediate **heat transfer** fluid is **pumped** to the second main **heat exchanger** which heats or cools the test fluid. The intermediate **heat transfer** fluid is water containing a corrosion inhibitor. Temperature probes are placed at the inlets and outlets of the main **heat exchanger** to gather **heat transfer** data. A solenoid **valve** is placed in the water/steam drain line in order to increase the pressure and...pressure taps drilled 45 cm apart near the center of the pipe. They do not **disturb** the flow field in the pipe. The entrance length from the last **disturbance** before the pressure taps (the flow control **valve**) exceeds 50 times the diameter of the pipe in order that the taps should be...though 7

Example 1 is an aqueous composition containing 0.2 percent of a viscoelastic **surfactant** of cetyltrimethyl ammonium salicylate prepared by admixing equimolar

amounts of cetyltrimethylammonium chloride and sodium salicylate 50(deg)C and 60(deg)C. The intermediate heat transfer fluid is at 70(deg)C. The temperatures of the intermediate heat transfer fluid entering and leaving the annulus of the main heat exchanger and the temperature of the test fluid entering and leaving the main heat exchangers are measured at the different mass flow rates. The overall heat transfer coefficient of the test fluids is calculated using the equations:

$$Q = UA \Delta T_{lm} = m C_p (t_2 - t_1) \dots \text{BTU/lb} \cdot (\text{deg})\text{F}$$

$\Delta T$  = temperature rise of the test fluid passing through the main heat exchanger ( $t_2 - t_1$ ), in (deg)F

$U$  = overall heat transfer coefficient in BTU/(lb  $\cdot$  (deg)F  $\cdot$  ft<sup>2</sup>) W/(m<sup>2</sup>  $\cdot$  K)

$A$  = is area of heat exchanger in ft<sup>2</sup>

$\Delta T_{lm}$  = logarithmic mean temperature drop in (deg)F  $\frac{(T_2 - t_1) - (T_1 - t_2)}{\ln(T_2 - t_1) - \ln(T_1 - t_2)}$

$T_1/T_2$  = temperature of the intermediate heat

transfer fluid entering/leaving the annulus of the main heat exchanger in (deg)F temperature of the test fluid entering/leaving the main heat exchanger

Data concerning the effect of the temperature and the mass flow rate on the overall heat transfer coefficient  $U$  is presented in Table I

O

C

O

TABLE I

O

O

W

lb Mass Flow Rate

Temp,  $T_1$  (deg)C / (hr  $\cdot$  ft<sup>2</sup>)  $\times 10^6$

Overall Heat Transfer Coefficient of Test Fluid [Kg/(sec  $\cdot$  m<sup>2</sup>)  $\times 10^5$ ]

BTU/(lb  $\cdot$  (deg)F  $\cdot$  ft<sup>2</sup>) [W/(m<sup>2</sup>  $\cdot$  ...coefficient  $U$  of the fluid

containing the viscoelastic

surfactant returns to that of water

The heat transfer data in Table I follows the same trend with increasing temperatures or mass flow rate as pipe flow friction reduction data. As the temperature is increased or the mass flow rate is increased, 10...

...of the

solvent (in this case water). The critical temperatures and critical flow rates for drag reduction are somewhat higher for pipe flow friction data than they are for the heat transfer data. Since the trends are the same, the pipe flow friction critical temperatures and critical flow rates can be used to predict the performance of the overall heat transfer coefficient

Example 3 is an aqueous composition containing 0.2 percent cetyltrimethylammonium salicylate and 0...composition containing 0.2 percent erucyltrimethyl

ammonium salicylate and 0.2 percent sodium salicylate

Fanning Friction Factors for Examples 1, 3, 4, 5, 6 and 7 are calculated for each composition...

...Reynolds Numbers between

60,000 and 965,000 using the equation:

DA P2 i  
Fanning Friction Factor 4pLV2

wherein: D = diameter in cm of the circular conduit through which the liquid...the liquid flows

V = velocity in cm/sec of the aqueous liquid

The minimum Fanning Friction Factors for each temperature are reported in Table II

Temp. T1'(deg)C Minimum Fanning Friction Factor X10  
of Test Ex. Ex. Ex. Ex. Ex

Fluids 1 3 4 5...56 2.30

-- -- -- 4.29 2.23

The data in Table II illustrate that the

surfactant ion and excess counterion can raise the critical temperature at which the minimum Fanning Friction Factor is observed

The data in Tables I and II illustrate that the critical temperature and critical mass flow rate depend on both the surfactant ion structure and counterion concentration in the test fluid. Thus, viscoelastic surfactant formulations can be designed in order to match the temperature conditions and flow rate requirements in a wide variety of heat transfer applications

Claim

CLAIMS

1. A method for controlling the overall heat transfer coefficient of a heat exchange fluid characterized (A) by incorporating in the heat exchange fluid a functionally effective amount of a viscoelastic surfactant composition which comprises (1) a surfactant compound having a hydrophobic moiety chemically bonded to an ionic, hydrophilic moiety and (2) an electrolyte having a moiety that is capable of associating with the surfactant ion to form a viscoelastic surfactant and (B) by providing a flow rate and a temperature of the heat exchange fluid such that the heat transfer fluid has the desired overall heat transfer coefficient.

...further amount of an electrolyte having a moiety that is capable of associating with the surfactant ion.

3. The method of Claim 1 characterized in that the viscoelastic surfactant composition is employed in an amount from 0.01 to 10 weight percent based upon the weight of the heat exchange fluid containing the surfactant composition.

4. The method of Claim 2 characterized in that the further amount of the electrolyte is from 0.1 to 20 moles per mole of the viscoelastic **surfactant** composition.

5. The method of Claim 3 characterized in that the temperatures of the **heat exchange** fluid is between -40(deg)C and 150(deg)C.

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00805096

USE OF A BETAINES SURFACTANT TOGETHER WITH AN ANIONIC SURFACTANT AS A  
DRAG -REDUCING AGENT

VERWENDUNG EINES BETAINENSIDES ZUSAMMEN MIT EINEM ANIONISCHEN TENSID ALS  
STROMUNGSBESCHLEUNIGER

UTILISATION D'UN TENSIOACTIF BETAINES AVEC UN TENSIOACTIF ANIONIQUE , EN  
TANT QU'AGENT DE REDUCTION DE RESISTANCE A L'ECOULEMENT

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Available Text	Language	Update	Word Count
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CLAIMS B	(English)	9843	403
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CLAIMS B	(German)	9843	373
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CLAIMS B	(French)	9843	449
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SPEC B	(English)	9843	2459
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Total word count - document A	0
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Total word count - document B	3684
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Total word count - documents A + B	3684
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USE OF A BETAINES SURFACTANT TOGETHER WITH AN ANIONIC SURFACTANT AS A  
DRAG -REDUCING AGENT

VERWENDUNG EINES BETAINENSIDES ZUSAMMEN MIT EINEM ANIONISCHEN TENSID ALS  
STROMUNGSBESCHLEUNIGER

UTILISATION D'UN TENSIOACTIF BETAINES AVEC UN TENSIOACTIF ANIONIQUE , EN  
TANT QU'AGENT DE REDUCTION DE RESISTANCE A L'ECOULEMENT

INTERNATIONAL PATENT CLASS: C10M-173/02 ...

... C09K-003/00

SPECIFICATION The present invention relates to the use of a betaine  
surfactant together with an anionic , surface active sulphate or  
sulphonate in a water-based system for reducing the flow resistance  
between a solid surface and the water-based liquid system.

Surfactants with the ability to form extremely long, cylindrical  
micelles have, in recent years, attracted a great interest as drag  
-reducing additives to systems with circulating water, especially those  
destined for heat or cold distribution...

...maintain a laminar flow in the conduits, one wishes at the same time to  
have turbulence in the heat exchangers to achieve therein a high

heat transfer per unit area.

As may easily be understood, fibres or chain polymers are unable to provide this double function which, however, can be achieved with thread-like **micelles**, since the flow rate (the Reynold's number) usually is much higher in the **heat exchangers** than in the conduit.

The thread-like **micelles** are distinguished by operating in a fairly disorderly fashion at low Reynold's numbers (below...

...very slight effect on the flow resistance. At higher Reynold's numbers (above 104)), the **micelles** are paralleled and result in a **drag** reduction very close to that which is theoretically possible. At even higher Reynold's numbers (e.g. above (105)), the **shear** forces in the liquid become so high that the **micelles** start to get torn and the **drag**-reducing effect rapidly decreases as the Reynold's number increases above this value.

The range of Reynold's numbers within which the **surface - active** agents have a maximum **drag**-reducing effect is heavily dependent on the concentration, the range increasing with the concentration.

By choosing the right concentration of **surface - active** agents and suitable flow rates in tubings and **heat exchangers**, it is thus possible to establish a laminar flow in the tubes and **turbulence** in the **heat exchangers**. Thus, the dimensions of both the tubes and the exchangers can be kept at a low level, or the number of **pump** stations, and consequently the **pump** work, can alternatively be reduced while retaining the same tubular dimensions.

The **surface active** agents most commonly used as **drag**-reducing additives to circulating water systems for heat or cold distribution are of the type...

...which may either be saturated or contain one or more double bonds.

This type of **surface - active** agent functions satisfactorily already at a concentration of 0.5-2 kg/m<sup>3</sup>), but is **degraded** very slowly, both aerobically and anaerobically, and further is highly toxic to marine organisms.

Since...

...criterion for a product injurious to the environment.

Thus there is a general demand for **surface - active** agents which are less harmful to the environment but which have the same excellent ability ...

...2-4 carbon atoms and n is 3-12, are capable of forming long cylindrical **micelles** in water and thus reduce the **drag** in water-based system.

These products are easily **degradable** and function excellently in deionized water especially at low temperatures. However, the **drag**-reducing effects are hampered in hard water and by the presence of high amounts of electrolytes. Further the temperature range for their optimal **drag**-reducing effect will be rather narrow, sometimes as small as 10(degree)C.

SE-C2-500 923 discloses the use of amphoteric **surfactants** as **friction** reducing agents in water-based systems. The amphoteric compounds, which contain one or more primary...

...been found that essential improvements are achieved by the use of at least one betaine **surfactant** having a saturated or unsaturated alkyl or acyl group with 10-24, preferably 14-24 carbon atoms in combination with an **anionic surfactant** having the general structure where R1)) is an hydrocarbon group with 10-24 carbon atoms and B is a group or a group in which M is a **cationic**, preferably monovalent group, in a proportion between the betaine **surfactant** and the **anionic surfactant** of from 20:1 to 1:2, preferably within 10:1 to 1:1, for...

- ...flow resistance between the flowing water-based liquid system and a solid surface. The betaine **surfactant** has preferably the general formula where R is the alkyl group or the group R...
- ...hydrophobic group R1)) can be aliphatic or aromatic, straight or branched, saturated or unsaturated. The **cationic** group B is suitably an alkali group like sodium or potassium. By "water-based" is...
- ...90% by weight, of the water-based liquid system consists of water. Both the betaine **surfactant** and the **anionic** **surfactant** are readily **degradable** and the combination gives an excellent **drag** reducing effect within a wide temperature range. Thus, the **drag** -reducing additives may be used in a cooling media at temperatures below 30(degree)C, when, for example using betaine **surfactants** , where the alkyl or acyl group has 14-16 carbon atoms, and in a **heat - transfer** medium at a temperature in the range of 50-120(degree)C, when, for example using betaine **surfactants** where the alkyl or acyl group contains 18 carbon atoms or more, preferably 18-22...
- ...that high carbon numbers will give products suitable for high temperatures.  
Furthermore, the betaine and **anionic** **surfactants** are suitably chosen in such a manner that the crystallization temperature for the combination is...
- ...temperature for which the water-based system is intended.  
The total amount of the betaine **surfactant** and the **anionic** **surfactant** may vary within wide limits depending on the conditions but is generally 0.1-10 kg/m<sup>3</sup>) of the water-based system.  
The solution of the betaine and **anionic** **surfactant** is especially suited for use in water-based systems flowing in long conduits, e.g. circulation water systems for heat and cold distributions.  
The betaine **surfactant** can be produced by reacting a N-alkyl-N, N-dimethylamine or a N'-acyl...
- ...9.5 in a medium of a lower alcohol or water. To obtain a good **drag** reducing effect it is essential that the amount of the amine reactant in betaine product...
- ...than 5% by weight and most preferably lower than 2% by weight of the betaine **surfactant** . If a low chloride content in the product is necessary the reaction can preferably be...
- ...oxide and an acid catalyst and then dehydrogenate the resulting product to the desired betaine **surfactant** . The group R and R' in formula I can suitably be tetradecyl, hexadecyl, octadecyl, oleyl, rape seed alkyl and tallow alkyl or the corresponding acyl group.  
The **anionic** **surfactants** suitable for use in accordance with the invention are well-known products and so are...
- ...tallow-sulphates and the corresponding sulphonates and dodecyl-bensensulphonates and hexadecylbensensulphonate.  
The choice of the **anionic** **surfactant** will depend on the hardness, the salt content and the temperature of the water. In...
- ...of their calcium salts.  
A convenient way to determine the right proportion between the betaine **surfactant** and the **anionic** **surfactant** for a certain type of water is to make up a solution of e.g. 0.500 kg/m<sup>3</sup>) of the betaine **surfactant** in the appropriate water in a glass beaker with a magnetic stirrer and keep

the...

...temperature range for the system. This solution is then titrated with a solution of the **anionic surfactant** with a concentration of 10 kg/m<sup>3</sup>) in deionized water until the originally formed **vortex** has disappeared.

The details of this procedure are described in more detail under the heading "Screening test".

Apart from the betaine and **anionic surfactant**, the water-based system may contain a number of conventional components such as rust-preventing...

...invention will now be further illustrated with the aid of the following examples.

#### Examples

The **drag** -reducing properties of the compositions and products according to the prior art have been tested...

...15 mm, the stirrer started at full speed, 1400 rpm, and the depth of the **vortex** formed in the solution was recorded at various temperatures.

When no **vortex** could be detected (recorded as 0 mm), it is known by experience that this indicates good **drag** reducing properties.

If on the other hand no efficient additive was present, e.g. for pure water the **vortex** reached down to the stirring magnet and the result was recorded as 35 mm.

Loop...

...of 8 mm and the other having an inner diameter of 10 mm. Water was **pumped** through the tube loop by a centrifugal **pump**, which was driven by a frequency-controlled motor for continuous adjustment of the flow rate...

...rotameter.

The straight parts of the tube loop had outlets which, with the aid of **valves**, could in turn be connected to a differential pressure gauge whose other side was all...

...tube loop. Further, the tube loop was heat-insulated, and the suction side of the **pump** was connected to a thermostatically controlled container with a volume of 20 l, to which measured were then converted into Moody's **friction** factor  $\gamma$  and are shown in the examples as a function of the Reynold's...

...examples also state the corresponding Prandtl number and Virk number. The former corresponds to the **friction** factor of water flow in **turbulence**, and the latter corresponds to flow without **turbulence**, i.e. a laminar flow.

#### Example 1

A modified sea-water was prepared by dissolving...

...and then tested at different temperatures from 8 to 24 (degree)C. The depth of **vortex** formed in mm at the stirrer speed of 1400 r.p.m. was measured. The...

...of a alkyl chain having a length of 16 carbon atoms in combination with an **anionic surfactant** can be used for cold water applications.

#### Example 2



In 40 mls of deionized water...

...Example 2 indicates that a combination of C18))-betaine and Na-LAS has a good **drag** -reducing effect in the temperature range 30-88(degree)C.

Example 3

The test was...

...the loop test method. Deionized water was used in the test.

The composition of the **drag** -reducing agent was 85 parts of C18))-betaine and 15 parts of Na-LAS and...

...From the loop test it may be concluded that the combination of N-alkylbetaine and **anionic surfactant** used has a low **drag** -reducing effect at 98(degree)C. These results are in good agreement with the results...

...value of the solution was 9.5. In the screening test this solution showed no **vortex** formation from 30(degree)C to 87(degree)C.

Example 5

15 mg active substance...

...The solution was heated slowly from room temperature up to 80(degree)C and the **vortex** depth observed in accordance with the screening test.

The following results were obtained.

These results show that this composition performs well as **drag** -reducing agent in the interval 30-75(degree)C.

- CLAIMS 1. Use of at least one betaine **surfactant** having a saturated or unsaturated alkyl or acyl group having 10-24, preferably 14-24 carbon atoms, in combination with at least one **anionic surfactant** having the general structure where R1) is a hydrocarbon group with 10-24 carbon atoms and B is a group or a group in which M is hydrogen or a **cationic**, preferably monovalent group, in a weight ratio between the betaine **surfactant** and the **anionic surfactant** of from 20:1 to 1:2, preferably in the range from 10:1 to 1:1 as a **drag** reducing additive in a flowing water-based liquid system.
2. Use as claimed in claim 1, characterized in, that the betaine **surfactant** of the general formula where R is the alkyl group or the group R'NC3...

...in claim 1, 2 or 3, characterized in, that the water-based system is a **heat - transfer** medium with a temperature in the range of 50-120(degree)C.

5. Use as...

...claimed in any one of claims 1-5, characterized in, that the mixture of betaine **surfactant** and **anionic surfactant** is added in an amount of 0.1-10 kg/m3) of the water-based...

24/3,K/23 (Item 23 from file: 348)  
DIALOG(R)File 348:EUROPEAN PATENTS  
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00792065

USE OF ALKOXYLATED ALKANOLAMIDE TOGETHER WITH ALKOXYLATED ALCOHOL AS A  
FRICTION -REDUCING AGENT

VERWENDUNG VON ALKOXYALKANOLAMID NEBEN ALKOXYALALKOHOL ALS  
REIBUNGSREDUZIEREND MITTEL

UTILISATION D'ALKANOLAMIDE ALCOXYLE CONJOINTEMENT AVEC DE L'ALCOOL ALCOXYLE  
COMME AGENT DE REDUCTION DE FRICTION

PATENT ASSIGNEE:

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PATENT (CC, No, Kind, Date): EP 804516 A1 971105 (Basic)

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APPLICATION (CC, No, Date): EP 96900586 960109; WO 96EP155 960109

PRIORITY (CC, No, Date): SE 95159 950119

DESIGNATED STATES: BE; DE; ES; FR; GB; IT; NL

INTERNATIONAL PATENT CLASS: C09K-003/00 ; C10M-173/02

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Available Text	Language	Update	Word Count
CLAIMS B	(English)	9831	352
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Total word count - document A			0
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Total word count - documents A + B			3584

USE OF ALKOXYLATED ALKANOLAMIDE TOGETHER WITH ALKOXYLATED ALCOHOL AS A  
FRICTION -REDUCING AGENT

UTILISATION D'ALKANOLAMIDE ALCOXYLE CONJOINTEMENT AVEC DE L'ALCOOL ALCOXYLE  
COMME AGENT DE REDUCTION DE FRICTION

INTERNATIONAL PATENT CLASS: C09K-003/00 ...

... C10M-173/02

...SPECIFICATION for reducing the flow resistance between a solid surface  
and the water-base liquid system.

**Surfactants** with the ability to form extremely long, cylindrical  
**micelles** have, in recent years, attracted a great interest as **friction**  
-reducing additives to systems with circulating water, especially those  
destined for heat or cold distribution...

...maintain a laminar flow in the conduits, one wishes at the same time to  
have **turbulence** in the **heat exchangers** to achieve therein a high  
**heat transfer** per unit area.

As may easily be understood, fibres or chain polymers are unable to  
provide this double function which, however, can be achieved with

rod-shaped **micelles** , since the flow rate (the Reynold's number) usually is much higher in the **heat exchangers** than in the conduit.

The rod-shaped **micelles** are distinguished by operating in a fairly disorderly fashion at low Reynold's numbers (below...

...very slight effect on the flow resistance.

At higher Reynold's numbers (above 104)), the **micelles** are paralleled and result in a **friction** reduction very close to that which is theoretically possible..

At even higher Reynold's numbers (e.g. above (105)), the **shear** forces in the liquid become so high that the **micelles** start to get torn and the **friction** -reducing effect rapidly decreases as the Reynold's number increases above this value.

The range of Reynold's numbers within which the **surface - active** agents have a maximum **friction** -reducing effect is heavily dependent on the concentration, the range increasing with the concentration.

By choosing the right concentration of **surface - active** agents and suitable flow rates in tubings and **heat exchangers** , it is thus possible to establish a laminar flow in the tubes and **turbulence** in the **heat exchangers** . Thus, the dimensions of both the tubes and the exchangers can be kept at a low level, or the number of **pump** stations, and consequently the **pump** work, can alternatively be reduced while retaining the same tubular dimensions.

The **surface active** agents most commonly used as **friction** -reducing additives to circulating water systems for heat or cold distribution are of the type...

...which may either be saturated or contain one or more double bonds.

This type of **surface - active** agent functions satisfactorily already at a concentration of 0.5-2 kg/m<sup>3</sup>), but is **degraded** very slowly, both aerobically and anaerobically, and further is highly toxic to marine organisms.

Since...

...criterion for a product injurious to the environment.

Thus there is a general demand for **surface - active** agents which are less harmful to the environment but which have the same excellent ability ...

...2-4 carbon atoms and n is 3-12, are capable of forming long cylindrical **micelles** in water and thus reduce the **friction** in water-based system.

These products are easily **degradable** and function excellently in deionized water especially at low temperatures. However, the **friction** -reducing effects are hampered in hard water and by the presence of high amounts of electrolytes. Further the temperature range for their optimal **friction** -reducing effect will be rather narrow, sometimes as small as 10(degree)C.

In the...

...961 639 it is disclosed that a solution of ethoxylated fatty alcohols may have good **friction** -reducing properties when it is tested at a temperature close to the cloud point of the solution and when the **surfactant** concentration is at least 5 and preferably 10 kg/m<sup>3</sup>).

We have now surprisingly found...

...the alkyleneoxy units consists of C<sub>2</sub>)H<sub>4</sub>)O units, will give water solutions with improved **friction** -reducing properties at low temperatures within a rather wide temperature range both below and above ...

...1:10, normally between 5:1 and 1:5. Besides the structure of the two **surfactant** components the weight ratio will also depend significantly on the hardness and salt content of...a demand for either a higher amount of the alkoxylated alcohol or a more hydrophilic **surfactant** of this type. A convenient way to find out the right proportion between the alkoxylated ...

...in the planned operational temperature range and then add successively a solution of the former **surfactant** until the dispersed alkoxylated alkanolamide just has been solubilized.

Suitable alkoxylated alcohols according to the...

...solubilisers, such as diethylene glycol monobutyl ethers, which may affect the cloud-point of the **surfactant** mixture in the water-base system quite considerably.

The present invention will now be further illustrated with the aid of the following examples.

#### Examples

The **friction** -reducing properties of the compositions and products according to the prior art have been tested...

...15 mm, the stirrer started at full speed, 1400 rpm, and the depth of the **vortex** formed in the solution was recorded at various temperatures while the solution temperature increased to room temperature during 15 mins.

When no **vortex** could be detected (recorded as 0 mm), it is known by experience that this indicates good **friction** reducing properties.

If on the other hand no efficient additive was present, e.g. for pure water the **vortex** reached down to the stirring magnet and the result was recorded as 35 mm.

Loop...

...of 8 mm and the other having an inner diameter of 10 mm. Water was **pumped** through the tube loop by a centrifugal **pump**, which was driven by a frequency-controlled motor for continuous adjustment of the flow rate...

...rotameter.

The straight parts of the tube loop had outlets which, with the aid of **valves**, could in turn be connected to a differential pressure gauge whose other side was all...

...tube loop. Further, the tube loop was heat-insulated, and the suction side of the **pump** was connected to a thermostatically controlled container with a volume of 20 l, to which...

...for each flow rate. The pressure differences thus measured were then converted into Moody's **friction** factor Y and are shown in the examples as a function of the Reynold's...

...examples also state the corresponding Prandtl number and Virk number. The former corresponds to the **friction** factor of water only, i.e. with **turbulence**, and the latter corresponds to flow without **turbulence**, i.e. a laminar flow.

#### Examples 1-3

These examples were carried out according to...  
...given in the table below:

The test results are given as the depth of the **vortex** formed in mm at the stirrer speed of 1400 rpm.

The results of these tests...

...the invention have a significant stabilizing effect on the water in immediate vicinity of a **turbulent** zone and have thus a good **friction** -reducing ability on water flowing in a tube, especially at low temperatures. The comparison tests show that the ethoxylated alcohol has only a limited **friction** -reducing effect at temperatures below 14(degree)C, while the ethoxylated ethanalamides in Comparison II show an excellent **friction** -reducing effect only within a narrow temperature interval (8-14(degree)C).

Examples 4-6...

...The water used had the same composition as the water in Examples 1-3. The **surfactants** added were 3.00 kg/m<sup>3</sup>) of OMA-5 and 3.00 kg/m<sup>3</sup>) of...

...with a composition according to the invention it can clearly be seen that a substantial **friction** -reducing effect can be achieved in the temperature range 6-21(degree)C in a...

...CLAIMS the range from 5:1 to 1:5 for reducing the flow resistance, depending on **turbulence** in a flowing water-base liquid system.  
2. Use as claimed in claim 1, characterized...

24/3,K/24 (Item 24 from file: 348)  
DIALOG(R)File 348:EUROPEAN PATENTS  
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00674093

USE OF ALKOXYLATED ALKANOLAMIDE AS FRICTION -REDUCING AGENT  
VERWENDUNG VON ALKOXYALKANOLAMID ALS REIBUNGSREDUZIERENDES MITTEL  
UTILISATION D'ALCANOLAMIDE ALCOXYLE EN TANT QU'AGENT REDUCTEUR DE  
FROTTEMENT

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PATENT (CC, No, Kind, Date): EP 646157 A1 950405 (Basic)  
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CLAIMS B	(English)	9710W4	267
CLAIMS B	(German)	9710W4	237
CLAIMS B	(French)	9710W4	285
SPEC B	(English)	9710W4	2242
Total word count - document A			0
Total word count - document B			3031
Total word count - documents A + B			3031

USE OF ALKOXYLATED ALKANOLAMIDE AS FRICTION -REDUCING AGENT  
INTERNATIONAL PATENT CLASS: C09K-003/00 ...

... C10M-105/04

...SPECIFICATION that the flow resistance of a liquid in a conduit is  
largely due to the **turbulence** that arises at the conduit wall. However,  
much of this **turbulence** can be prevented by adding to the liquid a  
sufficient amount of elongate particles. The...

...particles may vary within several orders of magnitude, from severed  
textile fibres, water-soluble chain **molecules** down to cylindrical  
**surfactant micelles**, i.e. within the range of 10<sup>-7</sup>-10<sup>-2</sup>) m. The  
reduction of the...

...in commercial hot-water systems, been assessed at 75%, which involves  
corresponding savings in supplied **pump** energy or, alternatively,  
permits further extension of the distributive network with the same **pump**  
installations.

In most cases, the addition of fibres is inconvenient, since various  
filters often are...

...in circulating liquid systems, and the water-soluble chain polymers are torn by the high **shear** forces in the pumps and thereby lose their effect.

**Surfactants** with the ability to form extremely long, cylindrical **micelles** have, in recent years, attracted a great interest as **friction**-reducing additives to systems with circulating water, especially those destined for heat or cold distribution...

...maintain a laminar flow in the conduits, one wishes at the same time to have **turbulence** in the **heat exchangers** to achieve therein a high **heat transfer** per unit area.

As may easily be understood, fibres or chain polymers are unable to provide this double function which, however, can be achieved with rod-shaped **micelles**, since the flow rate (the Reynold's number) usually is much higher in the **heat exchangers** than in the conduit.

The rod-shaped **micelles** are distinguished by operating in a fairly disorderly fashion at low Reynold's numbers (below...

...very slight effect on the flow resistance.

At higher Reynold's numbers (above 104)), the **micelles** are paralleled and result in a **friction** reduction very close to that which is theoretically possible.

At even higher Reynold's numbers (e.g. above 105)), the **shear** forces in the liquid become so high that the **micelles** start to get torn and the **friction**-reducing effect rapidly decreases as the Reynold's numbers increase.

The range of Reynold's numbers within which the **surface - active** agents have a maximum **friction**-reducing effect is heavily dependent on the concentration, the range increasing with the concentration.

By choosing the right concentration of **surface - active** agents and suitable flow rates in tubings and **heat exchangers**, it is thus possible to establish a laminar flow in the tubes and **turbulence** in the **heat exchangers**. Thus, the dimensions of both the tubes and the exchangers can be kept at a low level, or the number of **pump** stations, and consequently the **pump** work, can alternatively be reduced while retaining the same tubular dimensions.

The **surface - active** agents hitherto used as **friction**-reducing additives to circulating water systems - mainly destined for heat distribution - are all of the...

...which may either be saturated or contain one or more double bonds.

This type of **surface - active** agent functions satisfactorily already at a concentration of 0.5-1 g/l, but is **degraded** very slowly, both aerobically and anaerobically, and further is highly toxic to marine organisms.

In...

...097 it is also suggested to use quaternary ammonium compounds a flow increasing additive. The **cation** in these compounds has the formula where R1)) is an alkyl or alkylene residue with...

...a value from 1 to 3. However, even these quaternary ammonium compounds are only slowly **degradable** and highly toxic to marine organisms.

Since heat-distribution systems for small houses usually suffer...

...criterion for a product injurious to the environment.

Thus, there is a general demand for **surface - active** agents which are less harmful to the environment but which have the same excellent ability

...

...systems.

It has now surprisingly been found that a long since well-known type of **non - ionic surface - active** agents, namely alkoxyated alkanolamides, are capable of forming long cylindrical **micelles** . In flow tests in water-base systems, they had a **friction** -reducing effect well up to the effect achieved by the above-mentioned alkyltrimethyl ammonium salicylate...to the formula are wellknown and often used in detergent or cosmetic composition as cleaning **surfactants** or as thickening agents in aqueous concentrates. In US-A-3 676 344 it is...

...In order to reduce the increase in the yield point of the drilling fluid a **nonionic** compound having the formula wherein R is a hydrophobic group containing at least fourteen carbon...of 8 mm and the other having an inner diameter of 10 mm. Water was **pumped** through the tube loop by a centrifugal **pump** , which was driven by a frequency-controlled motor, for continuous adjustment of the flow rate...

...rotameter.

The straight parts of the tube loop had outlets which, with the aid of **valves** , could in turn be connected to a differential pressure gauge whose other side was all...

...tube loop. Further, the tube loop was heat-insulated, and the suction side of the **pump** was connected to a thermostatically controlled container with a volume of 20 l, to which...

...for each flow rate. The pressure differences thus measured were then converted into Moody's **friction** factor Y and are shown in the Table below as a function of the Reynold...

...Table also states the corresponding Prandtl number and Virk number. The former corresponds to the **friction** factor of water only, i.e. with **turbulence** , and the latter corresponds to flow without **turbulence** .

One of the following compounds was added as testing compound A Cetyl trimethyl ammonium salicylate...

...The following results were obtained.

As is apparent from these results, the invention gives a **friction** reduction down to the theoretically possible level (the Virk line), in analogy with prior-art results with alkyltrimethyl ammonium salicylate, and this is not possible with common **non - ionic surface - active** agents of the type fatty alcohol ethoxylate. Compared with the prior-art quaternary ammonium compounds, the **friction** -reducing agent according to the invention is advantageous in that it is much less toxic to water organisms and is biologically **degraded** much faster, both aerobically and anaerobically. The **friction** -reducing agent according to the invention may thus be used as a **friction** -reducing additive also to heat-distribution systems where there is a certain amount of leakage.



24/3,K/26 (Item 26 from file: 348)  
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00567908

Process for producing powdery anionic surfactant  
Verfahren zur Herstellung von pulverformigen, anionischen Tensiden  
Procede pour la preparation d'agent tensioactif anionique pulverulent  
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CLAIMS B	(French)	9804	332
SPEC B	(English)	9804	3955
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Total word count - document B			4838
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Process for producing powdery anionic surfactant  
Verfahren zur Herstellung von pulverformigen, anionischen Tensiden  
Procede pour la preparation d'agent tensioactif anionique pulverulent  
...INTERNATIONAL PATENT CLASS: C11D-001/29 ...

... C11D-001/14 ...

... C11D-001/26 ...

... C11D-011/00

...ABSTRACT A2

The process for producing a powdery anionic surfactant according to the present invention, wherein a powdery anionic surfactant is produced by using an evaporator having a heat transfer wall and rotating blades rotating along the inner surface of the heat transfer wall, which comprises feeding the anionic surfactant in the form of an aqueous slurry thereof having a solid concentration of from 60 to 80 wt.% into the evaporator, forming a film of the anionic surfactant on the inner surface of the heat transfer wall by rotating the blades, and scraping the film from the inner heat transfer wall with the rotating blades and powdering while continuously concentrating and drying

the aqueous **anionic surfactant** slurry.

**SPECIFICATION** This invention relates to a process for producing a powdery **anionic surfactant** from an aqueous slurry containing an **anionic surfactant**.

Powdery **anionic surfactants** are blended with other **surfactants** or builders to be used not only in clothing detergents and kitchen detergents but also in foaming agents for dentifrices, powdery shampoos and cleansing agents.

Known processes for drying an **anionic surfactant** into a powder or grains include ones comprising spray-drying a low-concentration slurry of ...

...thin-film drying method, it cannot provide a technically satisfactory process for producing a powdery **anionic surfactant** per se.

EP-A-0466243 discloses a process for preparing secondary alkyl sulfate-containing **surface active** compositions substantially free of unreacted organic matter and water, said process comprising (a) sulfating a...

...sulfuric acid, (b) neutralizing the product of step (a) with a base dispersed in a **nonionic surfactant** having a boiling point higher than that of said detergent range olefin and its corresponding...

...The object of the present invention is to provide a process for producing a powdery **anionic surfactant** which is little contaminated with impurities.

The above object has been solved by providing a process for producing a powdery **anionic surfactant** which is selected from the group consisting of alkyl sulfates having a linear or branched...

...oxide of at least 0.5, or a mixture of said salts wherein said powdery **anionic surfactant** is produced by using an evaporator having a **heat transfer** wall and rotating blades rotating along the inner surface of said **heat transfer** wall, which comprises feeding said **anionic surfactant** in the form of an aqueous slurry thereof having a solid concentration of from 60 to 80 wt.% into said evaporator, forming a film of the **anionic surfactant** on the inner surface of said **heat transfer** wall by rotating said blades, and scraping the film from the inner **heat transfer** wall with the rotating blades and powdering while continuously concentrating, drying the aqueous **anionic surfactant** slurry and blowing air, an inert gas or steam into the evaporator, wherein the ratio...

...is 2 parts by weight or above per 100 parts by weight of the aqueous **anionic surfactant** slurry.

The evaporator used in the present invention comprises a **heat transfer** wall and blades rotating along the inner surface of the **heat transfer** wall (hereinafter referred to as the inner **heat transfer** wall).

The present invention makes it possible to produce a high-quality powdery **anionic surfactant** which is white, has a high bulk density and is little contaminated with impurities by...

...be described.

The clearance (spacing) between the tip of the rotating blades and the inner **heat transfer** wall is 10 mm or below.

In the step of feeding the aqueous **anionic surfactant** slurry into the evaporator, the temperature of the aqueous slurry is controlled to be within a range of from 50 to 140(degree)C.

The temperature of the inner **heat transfer** wall of the evaporator is controlled to be within a range of from 50 to...

...least one gas selected from among air, an inert gas having no reactivity with the **anionic surfactant** and steam is continuously fed into the evaporator at a weight ratio of at least 20 parts by weight per 100 parts by weight of the aqueous **anionic surfactant** slurry to thereby give a powdery **anionic surfactant** little contaminated with impurities.

The moisture content of the powdery **anionic surfactant** obtained from the aqueous **anionic surfactant** slurry is adjusted to 10% by weight or below.

The bulk density of the powdery **anionic surfactant** obtained from the aqueous **anionic surfactant** slurry is adjusted to 0.4 g/ml or above.

The color of a 10 wt.% aqueous solution of the powdery **anionic surfactant** obtained from the aqueous **anionic surfactant** slurry is adjusted to KLETT No. 10 or below.

The rotary thin-film evaporator to be used in the process for producing a powdery **anionic surfactant** according to the present invention is not particularly restricted, so long as it has a basic construction comprising a **heat transfer** wall which supplies heat to the aqueous **anionic surfactant** slurry and rotating blades which form a film of the **anionic surfactant** on the inner surface of this **heat transfer** wall and scrape the film thus formed therefrom. The rotary thin-film evaporator may have...

...rotary thin-film evaporator is one comprising a cylindrical casing vertically set up as the **heat transfer** wall and rotating blades which rotate while sliding on the inner surface of the **heat transfer** wall or in close thereto as the rotating blades. The cylindrical casing may be provided at the upper part thereof with a feeding port for the aqueous **anionic surfactant** slurry and at the lower end thereof with a discharging port for a dried powdery **anionic surfactant**. Further, the cylindrical casing may be provided on the inner surface thereof with a heating...

...heating jacket, whereby the inner surface of the cylindrical casing can serve as the inner **heat transfer** wall.

In such a construction, the aqueous **anionic surfactant** slurry fed into the rotary thin-film evaporator is rubbed against the inner **heat transfer** wall by the action of the tips of the rotating blades to thereby form a...

...of the aqueous slurry. In this step, the formed film runs down along the inner **heat transfer** wall while receiving the **heat transferred** from the jacket and the heat of **friction** evolving between the rotating blades and the film of the aqueous slurry on the inner **heat transfer** wall, thus being gradually concentrated and dried. The **anionic surfactant** thus dried is scraped off by the rotating blades and formed into a powdery, granular...

...flaky product which is then taken out of the discharging port. Accordingly, the term "powdery **anionic surfactant**" as used herein refers to an **anionic surfactant** in the powdery, granular or flaky form.

On the other hand, the steam evaporated from the aqueous **anionic surfactant** slurry is condensed and recovered with, for example, a condenser located outside the evaporator.

In this process, it is important that the solid concentration of the aqueous **anionic surfactant** slurry is from 60 to 80% by weight, preferably from 65 to 75% by weight...

...handled, but the drying load is increased.

Examples of the method for preparing an aqueous **anionic surfactant** slurry of a solid concentration of from 60 to 80% by weight include one comprising...

...high solid concentration by taking advantage of the minimum viscosity of an aqueous slurry.

The **anionic surfactant** used in the present invention is one or more sulfuric acid salt selected from the...

...ethylene oxide or propylene oxide of at least 0.5, preferably 1 to 8.

The **anionic surfactant** is specifically represented by the following formulae (I) and (II).

Alkyl sulfate:

wherein R is...

...m is an average number of moles of addition of at least 0.5.

These **anionic surfactants** include alkali metal salts, ammonium salts and alkanolamine salts, among which alkali metal salts are...

...adducts thereof with an alkylene oxide compound (for example, ethylene oxide or propylene oxide). The **anionic surfactant** thus produced may contain unreacted matters after the sulfation in an amount of 20 wt.% or below, preferably 10 wt.% or below.

Further, additives other than the **anionic surfactant** may be added to the aqueous **anionic surfactant** slurry. The additives include alkaline agents such as silicates, carbonates and sesqui-carbonates (for example...

...a small amount, if necessary. In order to maintain the solid concentration of the powdery **anionic surfactant** as high as possible, it is preferable to use ...by weight or less per 100 parts by weight of the active ingredient of the **anionic surfactant**.

When the aqueous **anionic surfactant** slurry is fed into the rotary thin-film evaporator, the temperature of the slurry is...

...the temperature of the aqueous slurry exceeds 140(degree)C, on the other hand, the **anionic surfactant** undergoes decomposition.

In order to maintain the above-specified temperature of the slurry, it is preferable to appropriately heat the inner **heat transfer** wall of the rotary thin-film evaporator. For example, the inner **heat transfer** wall is preferably maintained at a temperature of from 50 to 140(degree) C, still...

...or hot water into, for example, the heating jacket. When the temperature of the inner **heat transfer** wall is below the lower limit as specified above, the drying rate of the slurry is lowered to lower the efficiency. When the temperature of the inner **heat transfer** wall exceeds the upper limit as specified above, on the other hand, the **anionic surfactant** is liable to undergo decomposition or color tone change. The temperature of the inner **heat transfer** wall can be measured by contacting a thermometer with the back surface of the inner wall. When the aqueous **anionic surfactant** slurry maintained at a given temperature is fed into the rotary thin-film evaporator, the aqueous slurry is rubbed against the inner **heat transfer** wall by the action of the tips of the rotating blades to thereby form a film.

The thickness of the **anionic surfactant** film is to be controlled to 10 mm or less, preferably 5 mm or less...

...For this purpose, the clearance between the tips of the rotating blades and the inner **heat transfer** wall of the rotary thin-film evaporator is to be controlled to 10 mm or...

...angle and a variable type unit where the angle between the blades and the inner **heat transfer** wall varies depending on the force applied thereto. The present invention is restricted to neither...

...a centrifugal thin-film evaporator provided with rotating blades whereby a film of an aqueous **anionic surfactant** slurry is formed by the centrifugal force of the rotating blades. Since the final product...

...as described above, the aqueous slurry is rapidly concentrated and dried by the heat of **friction** evolving between the rotating blades and the film of the aqueous slurry on the inner **heat transfer** wall and the **heat transferred** from the inner **heat transfer** wall. The **anionic surfactant** thus dried is scraped off with the rotating blades to give a powdery, granular or...

...is low and a small-scale apparatus is sufficient for the purpose.  
Since the powdery **surfactant** obtained by the production method as described above is under a shearing stress in the...

...which is effective in saving the transportation cost. Further, the water content of the powdery **surfactant** can be reduced to 10 wt.% or below. Furthermore, the process of the present invention makes it possible to produce the powdery **anionic surfactant** within a short period of time at a low heating temperature, thus preventing thermal deterioration... reduced pressure. In addition to this dry atmosphere condition, in order to obtain a powdery **anionic surfactant** of improved qualities, air, an inert gas or steam is blown into the rotary thin-film evaporator to lower the content of the impurities such as unreacted alcohol in the **anionic surfactant**, whereby a high-quality powdery **anionic surfactant** with reduced odor can be obtained.  
More specifically, when air, an inert gas or steam...

...film evaporator, the partial pressures of the unreacted alcohol and the by-products in the **anionic surfactant** are lowered and thus the evaporation of the unreacted alcohol and the by-products is...

...any form of a counter flow, a parallel flow or a cross flow against the **anionic surfactant** formed into film. Any inert gas may be selected, so long as it has no reactivity with the **anionic surfactant**. Examples thereof include helium, nitrogen, argon and carbon dioxide, among which nitrogen and carbon dioxide...

...from 5 to 500 parts by weight, per 100 parts by weight of the aqueous **anionic surfactant** slurry. It is not preferable to blow less than 2 parts by weight of the...

...the following Example and Comparative Examples will be given.

(Measurement of color (KLETT No.))  
An **anionic surfactant** is dissolved in water in a concentration of 10 wt.%. Then the absorbance of this...

...gravity is placed just under the fixed chute and an appropriate amount of a powdery **anionic surfactant** is gently placed on the sieve.  
4) The voltage of a rheostat is gradually elevated...

...fed into a rotary thin-film evaporator (Hi-Evaolator, manufactured by

Sakura Seisakusho) having a **heat transfer** area of 10 m<sup>2</sup>) at a temperature of 70(degree)C and at a flow...

...of 300 kg/h and produced a powdery sulfate therein. In this step, the inner **heat transfer** wall was heated to 130(degree)C by passing a heating steam through the jacket...

...m/s) and the clearance between the tips of the rotating blades and the inner **heat transfer** wall was 1.5 mm, when the system was run without feeding any material. Table...

...was fed into a rotary thin-film evaporator (Sevcon, manufactured by Hitachi, Ltd.) having a **heat transfer** area of 0.3 m<sup>2</sup>) at a temperature of 100(degree)C and at a...

...of 10 kg/h and produced a powdery sulfate therein. In this step, the inner **heat transfer** wall of the evaporator was heated to 90(degree)C by passing hot water through...

...m/s) and the tips of the rotating blades came into contact with the inner **heat transfer** wall at a clearance of 0 mm, when the system ... any material. These rotating blades were ones of variable type and a film of the **anionic surfactant** was formed between the inner **heat transfer** wall and the tips of the rotating blades during the operation. Table 1 shows the...

...was fed into a rotary thin-film evaporator (Sevcon, manufactured by Hitachi, Ltd.) having a **heat transfer** area of 0.3 m<sup>2</sup>) at a temperature of 140(degree)C and at a...

...of 10 kg/h and produced a powdery sulfate therein. In this step, the inner **heat transfer** wall of the evaporator was heated to 80(degree)C by passing hot water through...

...m/s) and the tips of the rotating blades came into contact with the inner **heat transfer** wall at a clearance of 0 mm, when the system was run without feeding any material. Similar to the above Comparative Example 4, a film of the **anionic surfactant** was formed between the inner **heat transfer** wall and the tips of the rotating blades during the operation. During the operation, steam...

CLAIMS 1. A process for producing a powdery **anionic surfactant** which is selected from the group consisting of alkyl sulfates having a linear or branched...

...oxide of at least 0.5, or a mixture of said salts wherein said powdery **anionic surfactant** is produced by using an evaporator having a **heat transfer** wall and rotating blades rotating along the inner surface of said **heat transfer** wall, which comprises feeding said **anionic surfactant** in the form of an aqueous slurry thereof having a solid concentration of from 60 to 80 wt.% into said evaporator, forming a film of the **anionic surfactant** on the inner surface of said **heat transfer** wall by rotating said blades, and scraping the film from the inner **heat transfer** wall with the rotating blades and powdering while continuously concentrating, drying the aqueous **anionic surfactant** slurry and blowing air, an inert gas or steam into the evaporator, wherein the ratio...

...is 2 parts by weight or above per 100 parts by weight of the aqueous **anionic surfactant** slurry.

2. A process for producing a powdery **anionic surfactant** as claimed in claim 1, wherein the peripheral speed of the tip of the blades is

from 2 to 20 m/s.

3. A process for producing a powdery **anionic surfactant** as claimed in claim 1, wherein the temperature of the inner surface of the **heat transfer** wall is from 50 to 140(degree)C.
4. A process for producing a powdery **anionic surfactant** as claimed in claim 1, wherein the pressure in the evaporator is from 0.133...

24/3,K/31 (Item 31 from file: 348)  
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00436749

**Functional fluids.**

**Funktionelle Flüssigkeiten.**

**Fluides fonctionnelles.**

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CLAIMS B	(English)	EPAB95	645
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INTERNATIONAL PATENT CLASS: C10M-173/02 ...

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...ABSTRACT suspended solids are used as Functional Fluids, such as  
Drilling Fluids, Cutting Fluids, Hydraulic Fluids, Heat Transfer  
Fluids, Construction Muds and Lubricants.

...SPECIFICATION well as more conventional Lubricants for bearings, gears,  
machinery, and the like, Hydraulic Fluids, and Heat Transfer Fluids.  
"Drilling Fluid" is used herein to refer to fluids used in the drilling  
of...



...in civil engineering and the construction industry to stabilise holes and excavations by preventing the **breakdown** of shales on exposure to water.

"Shaping" means any process for altering the shape of a solid workpiece by means of a tool, in which **friction** is generated, including drilling, cutting, grinding, boring, reaming, bending, stamping, pressing, hammering and the like...

...stamps, presses, broaches, reamers, grindstones and the like.

"Lubricant" means, generally, a fluid which reduces **friction** between moving surfaces and specifically includes Cutting Fluids, Drilling Fluids, and lubricating fluids for bearings, gears, machinery, hinges and sliding surfaces.

"**Heat Transfer** Fluid" means a fluid which is used to transfer heat from a warmer to a...

...systems, shock absorbers and fluidic logic circuits.

"Functional Fluid" as used herein means a Lubricant, **Heat Transfer** Fluid or Hydraulic Fluid.

"Electrolyte" is used herein to denote those ionic compounds which dissociate...

...provide ions, and which at the concentrations present tend to lower the total solubility (including **micellar** concentration) of **surfactants** in such solutions by a "salting out" effect. References herein to the Electrolyte content or concentration refer to the total dissolved Electrolyte, but excludes any suspended solid.

"**Micelle**" refers to a particle, which is either spherical or rod shaped, formed by aggregation of the **surfactant molecules** and having a radius less than twice the mean length of the **surfactant molecules**. The **molecules** in a **Micelle** are typically arranged such that their hydrophilic ("head") groups lie on the surface of the **Micelle** and the lipophilic ("tail") groups are in the interior of the **Micelle**.

"Bilayer" includes a layer of **surfactant** approximately two **molecules** thick, which is formed from two adjacent parallel layers, each comprising **surfactant molecules** which are disposed such that the lipophilic portions of the **molecules** are located in the interior of the Bilayer and the hydrophilic portions are located on...

...surfaces. "Bilayer" is also used herein to include interdigitated layers, which are less than two **molecules** thick. An interdigitated layer may be regarded as a Bilayer in which the two layers have interpenetrated allowing at least some degree of overlap between the tail groups of the **molecules** of the two layers.

"Spherulite" means a spherical or spheroidal body having dimensions of from...

...means a Vesicle which contains one or more smaller Vesicles. The Spherulites present in structured **surfactant** systems are typically concentric Multiple Vesicles.

"Lamellar Phase" means a hydrated solid, or liquid crystal...

...in the literature as "neat" phase or "lamellar" phase. The "G" phase for any given **surfactant** or **surfactant** mixture normally exists in a narrow range of concentrations. Pure "G" phases can normally be...

...to 150 nm.

"Spherical G Phase" means Multiple Vesicles formed from substantially concentric shells of **surfactant** Bilayer alternating with aqueous phase with a "G" phase or Expanded G phase spacing. Typically...

...the Lye phase.

"Lamellar Composition" means a composition in which a major part of the **surfactant** is present as a Lamellar Phase, or in which a Lamellar Phase is the principal factor inhibiting sedimentation. "Spherulitic Composition" means a composition in which a major part of the **surfactant** is present as ...G-phase, or which is principally stabilised against sedimentation by a Spherical G-phase.

"Structured **Surfactant** " means a fluid composition which has **shear** dependent viscosity and solid-suspending properties and which comprises a **surfactant** mesophase, which may optionally be dispersed in, or interspersed with an aqueous phase which is...

...Our invention concerns a solution to this problem which entails the use of aqueous Structured **Surfactants** , which are generally more environmentally acceptable than mineral oils, do not present a fire hazard...

...particular importance in the provision of Drilling Muds.

Drilling Fluids in oil wells are normally **pumped** continuously down the drill stem, through apertures in the drill bit and are then forced...

...acceptable Drilling Fluid needs to have a viscosity which is sufficiently low under conditions of **shear** to flow readily, but it also has to possess solid suspending properties. To achieve these conflicting requirements a thixotropic fluid is usually required. Moreover it must not cause excessive **breakdown** of rocks such as shale. If it is to be useful for deep drilling, the...

...have insufficient thermal stability to withstand the high temperatures of deep formations and they cause **breakdown** of the shale. Their lubricity is also generally inferior to that of oil based muds...

...insoluble in water. These problems have been solved by utilising the interaction between Electrolytes and **surfactants** to provide solid suspending structures based on thixotropic dispersions or interspersions of **surfactant** mesophases with aqueous Electrolyte solutions.

GB 2,123,846 describes the use of Lamellar **surfactant** interspersed with an Electrolyte solution in liquid laundry detergent. A different structure, also referred to...other publications; comprises an array of Spherulites, each having a plurality of concentric shells of **surfactant** alternating with layers of Electrolyte solution. Patent specifications which describe formulations which probably exhibit Spherulitic...

...for preparing a close packed, space filling, structure, sufficiently robust to withstand various forms of **shear** and temperature **stress** , but sufficiently mobile to be readily poured. The method requires optimising Electrolyte concentrations within close...

...In our pending British Patent Application No. 2229634 we have described the use of Structured **Surfactants** for the support of pesticides.

Prior art Functional Fluids including oil based Drilling Muds and Lubricants have contained minor proportions of **surfactants** as emulsifying agents for the oil or as dispersants for sludge. The **surfactants** have typically been present essentially as monolayers surrounding colloidal size droplets or particles of oil...

...Electrolyte content as it passes through the hole.

We have now discovered that aqueous Structured **Surfactants** have surprisingly good lubricity for both rock and metal, even under extreme pressure conditions and in the absence of extreme pressure additives. In

addition, such Structured **Surfactants** exhibit the rheological characteristics required for a Drilling Fluid or Hydraulic Fluid and also the...

...oil or protective polymer. We believe that the shale is protected by a coating of **surfactant**. The fluid is easily separated from rock cuttings and any residual **surfactant** can easily be washed from the cuttings with water. The clean cuttings present no ecological hazard and may be safely dumped. The aqueous **surfactant** is a Structured **Surfactant** such as those formed by the interaction of **surfactant** with dissolved Electrolyte, preferably a Spherulitic system. Typically it comprises a **surfactant** /water mesophase interspersed with an aqueous or aqueous Electrolyte continuous phase.

An important and particularly...

...lower than with conventional Drilling Fluids, even without additives which are normally required. The Structured **Surfactants** can readily be formulated in a heat stable form for high temperature applications such as...

...In our invention both suspending properties and protection of shale are provided essentially by the **surfactant**, preferably in conjunction with some dissolved Electrolyte. While we do not wish to be limited thereby, we believe that the **surfactant** may coat shale particles reversibly. It may also help to maintain an optimum water activity. The **surfactant** is preferably present in our composition as spherical G-phase, dispersed Lamellar phase or **Micelles**.

Generally our invention provides the use of aqueous, Structured **Surfactants** as, or in, Functional Fluids.

According to one embodiment our invention provides the use of Structured **Surfactants** as, or in, Hydraulic Fluids.

According to a second embodiment our invention provides the use of Structured **Surfactants** as, or in, **Heat Transfer** Fluids.

According to a third embodiment our invention provides the use of Structured **Surfactants** to reduce **friction** between moving surfaces.

According to the latter embodiment our invention includes a method of lubricating bearing surfaces, gears and the like which comprises applying thereto an aqueous Structured **Surfactant**.

In particular our invention provides a method of drilling bore holes or of Shaping metal or other workpieces which comprises using as Drilling Fluid or Cutting Fluid an aqueous Structured **Surfactant** which is preferably a solution containing **surfactant Micelles**, or interspersed with a Lamellar solid, Spherulitic or G-phase **surfactant**, in a quantity sufficient to inhibit disintegration of shale or provide wear protection to metal...

...drilling conditions.

According to a further embodiment our invention comprises the use of aqueous Structured **Surfactants** as, or in, Construction Muds or Spacer Fluids.

According to a further embodiment our invention provides a Functional Fluid comprising an aqueous Structured **Surfactant** and a corrosion inhibitor dissolved therein.

According to a further embodiment our invention provides a Drilling Mud comprising an aqueous Structured **Surfactant** which preferably comprises: (A) a continuous aqueous phase, (B) a Lamellar solid, Spherulitic or G-phase **surfactant** structure interspersed with said aqueous phase; in an amount sufficient to confer solid suspending properties...embodiment, our invention further provides a Cutting Fluid or other Lubricant comprising an aqueous Structured **Surfactant** and containing wear inhibiting or lubricity promoting additives.

According to a further embodiment our invention provides a **Heat Transfer** Fluid comprising a particulate solid, having a high specific heat capacity such as ferrophosphorus.

The...

...least 3%, more usually at least 4%, e.g. at least 5% by weight of **surfactants**. The **surfactants** may constitute up to about 35% by weight of the composition, although we prefer on...

...less than 25%, preferably less than 20%, e.g. 10 to 15% by weight.

The **surfactant** may for example consist substantially of an at least sparingly water-soluble salt of sulphonic...

...groups, typically containing from 1 to 20 oxyalkylene groups. For example, the sulphonated or sulphated **surfactant** may be sodium dodecyl benzene sulphonate, potassium hexadecyl benzene sulphonate, sodium dodecyl dimethyl benzene sulphonate...

...potassium oleyl sulphate, ammonium lauryl monoethoxy sulphate, or monethanolamine cetyl 10 mole ethoxylate sulphate.

Other **anionic surfactants** useful according to the present invention include fatty alkyl sulposuccinates, fatty alkyl ether sulposuccinates, fatty...

...such as stearates, palmitates, resinates, oleates, linoleates, rosins soaps and alkyl ether carboxylates and saponins. **Anionic** phosphate esters including naturally occurring **surfactants** such as lecithin may also be used. In each case the **anionic surfactant** typically contains at least one aliphatic hydrocarbon chain having from 8 to 22 preferably 10...

...or more glyceryl and/or from 1 to 20 ethyleneoxy and/or propyleneoxy groups.

Preferred **anionic surfactants** are sodium salts. Other salts of commercial interest include those of potassium, lithium, calcium, magnesium...

...triethanolamine and alkyl amines containing up to seven aliphatic carbon atoms, such as isopropylamine.

The **surfactant** preferably contains or consists of **nonionic surfactants**. The **nonionic surfactant** may be e.g. a C(sub 1)(sub 0)-(sub 2)(sub 2) alkanolamide...

...a mono or di- lower alkanolamine, such as coconut or tallow monoethanolamide or diethanolamide. Other **nonionic surfactants** which may optionally be present, include ethoxylated alcohols, ethoxylated carboxylic acids, ethoxylated amines, ethoxylated alkylolamides...

...propoxylated, butoxylated and mixed ethoxy/propoxy and/or butoxy analogues of all the aforesaid ethoxylated **nonionics**, all having a C(sub 8)-(sub 2)(sub 2) alkyl or alkenyl group and up to 20 ethyleneoxy and/or propyleneoxy and/or butyleneoxy groups, or any other **nonionic surfactant** which has hitherto been incorporated in powder or liquid detergent compositions e.g. amine oxides...

...C(sub 1)-(sub 4), preferably C(sub 1)-(sub 2)) alkyl groups.

The preferred **nonionics** for our invention are for example those having an HLB range of 2-18 e.g. 8-18.

Our compositions may contain **cationic surfactants**, which include quaternary amines having at least one long chain (e.g. C(sub 1)...

...quaternised amido amines having at least one long chain alkyl or alkenyl group. The quaternised **surfactants** are all usually salts of **anions** which impart a measure of water solubility such as formate, acetate, lactate, tartrate, chloride, methosulphate, ethosulphate, sulphate or nitrate. Especially effective as Lubricants are **cationic surfactants** having two long chain fatty alkyl e.g. tallow groups, such as bis tallowyl quaternary ammonium and imidazolinium salts.

Compositions of our invention may also contain one or more amphoteric **surfactant**, which include betaines, sulphobetaines and phosphobetaines formed by reacting a suitable tertiary nitrogen compound having...

...groups and amidoamines having one or two long chain alkyl or alkenyl groups. Generally amphoteric **surfactants** are less preferred than **non - ionic**, or **anionic**, **surfactants**.

The specific **surfactant** types described above are only exemplary of the commoner **surfactants** suitable for use according to the invention. Any **surfactant** may be included. A fuller description of the principal types of **surfactant** which are commercially available is given in "Surface Active Agents and Detergents" by Schwartz Perry and Berch.

Generally we prefer that **surfactants** for use according to our invention should be substantially non-toxic, especially to marine life, we also prefer that the **surfactants** should be substantially stable at temperatures above 100(degree)C, preferably above 120(degree)C...

...compounds are strongly preferred constituents of our compositions. Although it is possible to prepare Structured **Surfactants** in the absence of Electrolyte, if the **surfactant** concentration is sufficiently high, the mobility of such systems is often insufficient unless the **surfactant** has been selected with great care. Addition of Electrolyte permits the preparation of mobile Structured **Surfactants** containing relatively low concentrations of **surfactant**.

Suitable Electrolytes include the water soluble alkali metal, ammonium and alkaline earth metal salts of...

...convenient, in the case of Drilling Fluids to make up the composition by diluting a **surfactant** concentrate on site with locally occurring natural brine (e.g. sea water in the case...

...Electrolyte may be present in concentrations up to saturation. Typically the less the amount of **surfactant** present, the more Electrolyte will be required to form a structure capable of supporting solid materials. We generally prefer to use higher concentrations of Electrolyte and lower concentrations of **surfactant**, and to select the cheapest Electrolytes on economic grounds. Thus Electrolyte should normally be present...

...of suspended solids. The optimum concentration of Electrolyte for any particular type and amount of **surfactant** may be ascertained as described in our aforesaid application by observing the variation of electrical...

...degree)C in an autoclave. Preferably also the Electrolyte content is adjusted to provide a **shear** stable composition and desirably, one which does not increase viscosity substantially on standing after exposure to normal **shearing**.

Alternatively sufficient Electrolyte may be added to form a Lamellar system as described in GB...

...centrifuging at 800G for seventeen hours to form a Lye phase containing little or no **surfactant**. The amount of water in the formulation may then be adjusted to obtain an optimum...

...usually desirable to supply to the hole a fluid that contains the necessary concentrations of **surfactant** and Electrolyte to form a solid-suspending structure. However Electrolyte salts occurring in the rock...

...drilled may sometimes be capable of forming the structure in situ if only an aqueous **surfactant** is supplied. It is often preferred to supply an aqueous system containing less than the...

...hole.

The quantity of Electrolyte required, also depends on the nature and solubility of the **surfactant**. Generally **surfactants** with high cloud points need less Electrolyte than **surfactants** with low cloud point. With some **surfactants** no Electrolyte is required.

The **surfactants** or **surfactant** mixtures that can be used in Electrolyte-free compositions according to the present invention are...

...temperature, but, preferably, do not form an M(sub 1) phase. Generally speaking the aqueous **surfactant** has a cloud point greater than 30(degree)C, more usually greater than 40(degree)C and preferably greater than 50(degree)C. Aqueous **surfactants** having a cloud point above 60(degree)C are especially suitable. Alternatively or additionally the **surfactant** may have an inverse cloud point below 30(degree)C, more usually below 20(degree)C, especially below 10(degree)C, preferably below 0(degree)C. **Surfactants** with an inverse cloud point below -10(degree)C are especially useful. Inverse cloud points are typical of some **nonionic surfactants**, in which increasing temperature tends to **break** the hydrogen bonds responsible for hydration of the hydrophilic part of the **molecule**, thus rendering it less soluble. Normal cloud points are more typical of **anionic** or **cationic surfactants**. Mixtures of **anionic** and **nonionic surfactant** may show a cloud point and/or an inverse cloud point.

It is usually preferred that the **surfactant** should be present in a concentration of at least 1% eg at least 3% by...

...especially above 8% and preferably 10% to 15%. A typical range of concentrations of the **surfactants** is from 6 to 15% more usually 7 to 12%. Other concentration of **surfactants** which may be used are 1-30% eg 2-15% by weight of the composition. We prefer that the concentration of **surfactant** should be sufficient, in the presence of any Electrolyte in the formulation to provide compositions...

...approximately to: 50 to 120; 70 to 95; 85 expressed in SI units.

Concentrations of **surfactant** above 60% are possible but very unlikely to be commercially viable at least for the majority of foreseeable uses of the invention.

Particularly preferred in Electrolyte-free systems are **nonionic** and mixed **nonionic surfactants**, especially mixtures of fatty alcohol ethoxylates and mixtures of fatty alcohol ethoxylates with fatty acid...

...alkoxylated with from 5 to 15 ethyleneoxy and/or propyleneoxy groups, are especially useful. Other **non-ionic surfactant** which may be used include alkoxylated alkylphenols, alkoxylated amines, alkoxylated sorbitan or glycerol esters of...

...to 1.8.

We prefer that the Functional Fluids of our invention should have low **foaming** properties. While this can be achieved by selecting inherently low **foaming surfactants**, we may be able to include antifoams such as

silicone oil antifoams, phosphate esters, fatty...

...urea, benzene sulphonate or lower alkyl benzene sulphonates. Solvents and hydrotropes tend to interfere with **surfactant** structuring and require the use of substantially increased amounts of **surfactant** and/or Electrolyte. They also increase the cost of the formulation without generally increasing performance...

...vegetables oils or solid lubricants such as graphite suspended or emulsified in the aqueous Structured **Surfactant** .

We prefer that polymeric thickening agents such as gums are absent or present in concentrations...

...in original document) (see image in original document)

Examples 1, 2 and 3 were clear **micellar** solutions. Examples 4 and 5 were opaque spherulitic compositions.

All five examples were capable of...only lubricant of the four to survive the test without failure.

Example 13

Various Structured **Surfactants** were compared with water, mineral oils and non-structured **surfactant** solutions in the test of Example 12. The results are set out in Table 2...

...CLAIMS B1

1. The use of aqueous Structured **Surfactants** comprising water and a **surfactant** structure which confers **shear** -dependent viscosity and solid-suspending properties as, or in, Functional Fluids selected from the group consisting of Lubricants, Hydraulic Fluids and **Heat Transfer Fluids**.
2. The use according to claim 1 of aqueous Structured **Surfactants** as, or in, Hydraulic Fluids.
3. The use according to claim 1 of aqueous Structured **Surfactants** as, or in, **Heat Transfer Fluids**.
4. The use according to claim 1 of aqueous Structured **Surfactants** to reduce **friction** between moving surfaces.
5. The use of aqueous Structured **Surfactants** as, or in, Drilling Fluids, Spacer Fluids or Construction Muds.
6. A method of lubricating...

...by applying thereto a fluid Lubricant characterized in that said Lubricant comprises an aqueous Structured **Surfactant** comprising water and a **surfactant** structure which confers **shear** -dependent viscosity and solid-suspending properties.

7. A method according to claim 6 of drilling...

...Shaping tool characterized in that said Drilling Fluid or Cutting Fluid comprises an aqueous Structured **Surfactant** .

8. A method according to either of claims 6 and 7 wherein said Structured **Surfactant** comprises an aqueous solution interspersed with a **surfactant** present as a Lamellar solid, Spherulites or G-phase in a quantity sufficient to provide...

...Shaping.

9. A Functional Fluid selected from the group consisting of Lubricants, Hydraulic Fluids and **Heat Transfer Fluids** comprising an aqueous Structured **Surfactant** comprising water and a **surfactant** structure which confers **shear** -dependent viscosity and solid-suspending properties and having dissolved therein a corrosion inhibitor.
10. A Drilling Mud comprising an aqueous Structured **Surfactant** comprising water and a **surfactant** structure which confers **shear** -dependent viscosity and solid-suspending properties .

11. A Drilling Mud according to claim 10 having...
- ...claims 10 and 11 containing suspended solid particles of barite and/or haematite.
13. A **Heat Transfer** Fluid comprising an aqueous Structured **Surfactant** comprising water and a **surfactant** structure which confers **shear** -dependent viscosity and solid-suspending properties having suspended therein particles of a solid heat storage medium.
14. A Lubricant comprising an aqueous Structured **Surfactant** comprising water and a **surfactant** structure which confers **shear** -dependent viscosity and solid-suspending properties containing wear inhibiting or lubricity promoting additives.
15. A...
- ...14.
16. A composition according to any of claims 9 to 15 wherein said Structured **Surfactant** comprises:
- (A) an aqueous phase;
- (B) a Lamellar solid, Spherulitic or G-phase dispersed in...
- ...to any of claims 9 to 20 containing from 5 to 45% by weight of **surfactant** based on the total weight of the composition.
22. A composition according to any of claims 9 to 21 containing sufficient dissolved Electrolyte to provide, with said **surfactant** , a stable, solid-suspending Spherulitic or Lamellar composition.
23. A hydraulic device containing a Hydraulic Fluid wherein said Hydraulic Fluid consists essentially of an aqueous Structured **Surfactant** comprising water and a **surfactant** structure which confers **shear** -dependent viscosity and solid-suspending properties.
24. A device comprising a heat source a heat sink and a **heat transfer** fluid able to contact each of said heat source and said heat sink, said **heat transfer** fluid consisting essentially of an aqueous Structured **Surfactant** comprising water and a **surfactant** structure which confers **shear** -dependent viscosity and solid-suspending properties.
25. A device comprising at least two surfaces movable relative to one another separated by a lubricating film of an aqueous Structured **Surfactant** comprising water and a **surfactant** structure which confers **shear** -dependent viscosity and solid-suspending properties.
- ...



24/3,K/39 (Item 39 from file: 349)  
DIALOG(R)File 349:PCT FULLTEXT  
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*INVENTORS*

00551082 \*\*Image available\*\*

METHODS TO CONTROL HEAT TRANSFER IN FLUIDS CONTAINING DRAG-REDUCING  
ADDITIVES

PROCEDES DE COMMANDE DE TRANSFERT DE CHALEUR DANS DES FLUIDES CONTENANT DES  
ADDITIFS REDUCTEURS DE PERTE DE POUSSEE

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Inventor(s):

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MATTHYS Eric F,

Patent and Priority Information (Country, Number, Date):

Patent: WO 200014455 A1 20000316 (WO 0014455)

Application: WO 99US20220 19990902 (PCT/WO US9920220)

Priority Application: US 98148029 19980903

Designated States: AL AM AT AU AZ BA BB BG BR BY CA CH CN CU CZ DE DK EE ES

FI GB GD GE GH GM HR HU ID IL IS JP KE KG KP KR KZ LC LK LR LS LT LU LV

MD MG MK MN MW MX NO NZ PL PT RO RU SD SE SG SI SK SL TJ TM TR TT UA UG

US UZ VN YU ZW GH GM KE LS MW SD SL SZ UG ZW AM AZ BY KG KZ MD RU TJ TM

AT BE CH CY DE DK ES FI FR GB GR IE IT LU MC NL PT SE BF BJ CF CG CI CM

GA GN GW ML MR NE SN TD TG

Publication Language: English

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International Patent Class: C10M ; ...

... C09K-005/00

Fulltext Availability:

Claims

Claim

... reducing surfactant solution as a thermal distribution fluid  
comprising:  
a surfactant solution flowing through said **heat exchanger** , which  
**surfactant** reduces fluid **drag** within said **hydronic** system, but not  
necessarily  
within said **heat exchanger** , said **surfactant** solution characterized by  
an  
optimized recovery time as defined by ability of said **surfactant**  
solution to rebuild molecular or **micellar** structures after disruption  
of said **molecular** or **micellar**  
structures; and  
a fluid **degradation** device to create temporary fluid **degradation** in  
said  
1 1 **heat exchanger** to break or disrupt said **molecular** or  
**micellar** structures in said surfactant solution by high local shear  
stresses so that heat transfer rate of said **surfactant** solution is  
increased in the **heat exchanger** for a predetermined  
distance or time downstream from said **degradation** device, during which  
1 5 recovery time said **molecular** or **micellar** structures are being  
**rebuilt** , subsequent  
1 6 to which full **drag** and heat **transfer** reductions are again  
achieved,  
obtained without **surfactant** to achieve overall energy savings in said  
**hydronic** 1 9 system.

2 An improvement in a method of heat exchange in a hydronic...

...as a heat exchanging fluid in a heat exchanger included within said hydronic system, which **surfactant** solution reduces fluid **drag** within said **hydronic0** system, said **surfactant** solution characterized by a predetermined recovery time as defined by ability of said **surfactant** solution to rebuild molecular or **micellar** structures after disruption of said **molecular** or **micellar** structures; and **disturbing** flow in said heat **exchanger** to **break** or **disrupt** said **molecular** or **micellar** structures in said surfactant solution by high local shear stresses so that **heat transfer** rate of said **surfactant** 1 1 solution is returned to a level approximating **heat transfer** rate of said heat exchanging fluid without said **surfactant** added for a predetermined distance downstream from said **disturbance** during said recovery time during which said molecular or micellar structures are being rebuilt.

3 A method of heat **transfer** recovery in turbulent flow of drag reducing **surfactant** solutions comprising  
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pressure drop;  
creating temporary **degradation** of a circulating fluid; and  
conditioning of the **drag** reducing fluid properties relevant for **degradation** and recovery.

4 A fluid having optimized properties of **degradation** and recovery comprising:  
a thermal transport fluid; and  
a **surfactant** additive capable of withstanding **stress** in all pipes and fittings of a circulation system and providing asymptotic **drag** reduction in straight pipes, and some **drag** reduction in fittings, whereas in a heat **exchanger** in which said fluid is **degraded** by a **degrading** device, the **drag** and heat **transfer** reductions are temporarily substantially eliminated, said fluid remaining substantially **degraded** during its residence in said heat **exchanger** after which recovery occurs quickly after said fluid exits from heat **exchanger** .  
1

5 The fluid of claim 4 where said fluid and **surfactant** in combination are characterized by a **drag** reduction recovery having a long dead time at substantially reduced **drag** reduction and a fast recovery to a substantially undegraded **drag** reduction level.  
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comprising:  
a thermal transport fluid; and  
a **surfactant** additive having, when added to said thermal transport fluid, a substantial independence of **drag** -reducing ability, **degradation** , and recovery properties as a function of temperature.

7 The fluid of claim 6 wherein said **surfactant** additive comprises a mixture of **surfactants** with opposing effects of temperature on **drag** -reducing ability, **degradation** , and recovery time.

8 The fluid of claim 7 where said mixture of **surfactants** comprises a **cationic surfactant** and a **nonionic surfactant** in which opposing effects of said **cationic surfactant** and **nonionic surfactant**

substantially cancel each other to provide a substantially **temperature independent** surfactant additive.

9 A heat exchanger comprising:

a first **heat exchanging** fluid path:

a second **heat exchanging** fluid path, wherein at least one of said first and second **heat exchanging** fluid paths further comprises a dedicated **degrading**

device disposed therein; and

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surfactant additive disposed in said corresponding **heat exchanging** fluid path.

10 The **heat exchanger** of claim 9 wherein said dedicated device is used exclusively for **degrading** a **heat exchanging** fluid flowing through said **heat exchanger**.

11 The **heat exchanger** of claim 9 wherein said dedicated **degrading** device imposes a flow **disturbance** or **shear stress** uniformly across a cross section of said corresponding **heat exchanging** fluid path in which said dedicated **degrading** device is disposed.

12 The **heat exchanger** of claim 11 wherein said dedicated **degrading** device exposes every surfactant particle flowing in said corresponding **heat exchanging** fluid path to at least a supercritical **stress**.

13 The **heat exchanger** of claim 12 wherein said **stress** imposed by said dedicated **degrading** device is not significantly higher than said supercritical **stress** so that the flow energy needed for **degradation** is minimized.

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device is disposed at or near an inlet to said corresponding **heat exchanging** fluid path.

15 The **heat exchanger** of claim 9 wherein said dedicated **degrading** device comprises a wire mesh disposed across said corresponding **heat exchanging** fluid path.

16 The **heat exchanger** of claim 15 wherein said wire mesh also functions as a filter.

17 A **heat exchanger** comprising:

a first **heat exchanging** fluid path;

a second **heat exchanging** fluid path, wherein at least a corresponding one of said first and second **heat exchanging** fluid paths further comprises a conventional hydraulic component normally found in a circulation system, which

hydraulic component is disposed upstream and in proximity to said corresponding **heat exchanging** fluid path; and

a **heat exchanging** fluid with a temporarily degradable drag reducing surfactant additive disposed in said corresponding **heat exchanging** fluid path.

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exchanger by means of a **drag** reducing **surfactant** fluid characterized by

**degradation** and recovery of **drag** reducing fluid properties comprising:

conditioning said **drag** reducing fluid properties of said **drag** reducing

**surfactant** fluid;

providing a **degrading** device which **degrades** the fluid with minimum pressure drop;  
creating an initial temporary **degradation** of a circulating fluid in a flow of  
said fluid in said heat **exchanger** ; and  
1 0 after said fluid is initially **degraded** , creating additional **disturbances** in said 1 1 flow to prevent recovery of the fluid.

19 The method of claim 18 where a smaller pressure drop than the one used for said initial **degradation** upstream of heat **exchanger** is used to create said smaller **disturbance** .

20 The method of claim 19 where conditioning said **drag** reducing fluid properties of said **drag** reducing **surfactant** fluid with a faster recovery to achieve asymptotic **drag** reduction immediately downstream from said heat **exchanger** .

21 The method of claim 19 where conditioning said **drag** reducing fluid properties of said **drag** reducing **surfactant** fluid by pipe **stress** to use **shear**

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**stress** generated by said heat **exchanging** fluid paths of said heat **exchanger** to **degrade** said fluid.

22 The method of claim 9 where conditioning said **drag** reducing fluid properties of said **drag** reducing **surfactant** fluid by pipe **stress** to use **shear stress** generated by said heat **exchanging** fluid paths of said heat **exchanger** to prevent said fluid **degraded** by said **degrading** device from recovering.

23 The improvement of claim 2 further comprising maintaining flow rate of said heat **exchanging** fluid in said **hydronic** system, while flow rate of said heat **exchanging** fluid in said heat **exchanger** is increased in the heat **exchanger** through the addition of a secondary **pump** located in parallel with the heat **exchanger** and connected to the inlet and outlet of the heat **exchanger** .

24 A fluid comprising:

a base component; and

a **surfactant** having **drag** -reducing, fluid **degradation** , and fluid recovery

properties which are substantially independent of temperature when combined with said base component.

25 A method of characterizing **degradability** of a fluid and **degradation** work imposed on a fluid comprising:

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providing a **degrading** device in said flow to **degrade** said **drag** reducing

properties of said fluid;

creating a pressure drop across said **degrading** device; and

measuring said pressure drop as an indicator of resistance to **degradation** of said **drag** reducing properties in said fluid, as well as an indicator of the **degradation** work imposed on the fluid.

26 A method of managing **degradability** of a fluid and **degradation** work imposed on a fluid comprising:

providing a flow of said fluid;

providing a **degrading** device in said flow to **degrade** said **drag** reducing

properties of said fluid;  
creating a pressure drop across said **degrading** device; and  
providing a predetermined amount of time after **degradation** of said  
**drag**

reducing properties of said fluid to allow recovery of said fluid without  
additional **degradation** work being performed, said predetermined amount  
of time being independent of velocity of said fluid.

27 A method of increasing heat **transfer** in a **hydronic** system having a  
heat **exchanger** over nominal design limits, said heat **exchanger** having  
a heat transport fluid therein which is characterized by a heat **transfer**  
rate, comprising:

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**hydronic** system;  
providing a flow of said heat transport fluid and said surfactant through  
said heat **exchanger** at an increased rate over said nominal design  
limits; and  
providing a **degrading** device in said flow in said heat exchanger to  
degrade said drag reducing properties of said surfactant in order to  
increase said heat **transfer** rate of said heat transport fluid in said  
heat **exchanger** .

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Set	Items	Description
S1	1	AU=(MATTHYS E? OR MATTHYS, E? OR GASLIEVIC K? OR GASLJEVIC K? OR GASLJIEVIC K? OR GASLIEVIC, K? OR GASLJEVIC, K? OR GASLJIEVIC, K?)
S2	0	ERIC(2W)MATTHYS OR (KAZIMIR OR CASIMIR) (2W) (GASLIEVIC OR GASLJEVIC OR GASLJIEVIC)
S3	0	AU=(BEWERSDORFF H? OR BEWERSDORFF, H?)
S4	0	H?(2W)BEWERSDORFF
S5	0	AU=(ZAKIN J? OR ZAKIN, J?)
S6	0	JACQUES(2W)ZAKIN
S7	2079	(DRAG? OR FRICTION? OR (HEAT? OR THERM?) (2N)EXCHANG?) AND - (SURFACTANT? OR SURFACE()ACTIVE)
S8	368910	IC=(F24H? OR C10M? OR C09K? OR F28F? OR F28D? OR C11D?)

? show files

File 347:JAPIO Nov 1976-2004/Jan(Updated 040506)

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File 350:Derwent WPIX 1963-2004/UD,UM &UP=200431

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1/3,K/1 (Item 1 from file: 350)  
DIALOG(R)File 350:Derwent WPIX  
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013085181 \*\*Image available\*\*  
WPI Acc No: 2000-257053/200022  
XRAM Acc No: C00-078617  
XRPX Acc No: N00-191052

Fluid for controlling heat transfer includes base component and  
surfactant having drag-reducing, fluid degradation and fluid recovery  
properties

Patent Assignee: UNIV CALIFORNIA (REGC )  
Inventor: GASLJEVIC K ; MATTHYS E F  
Number of Countries: 083 Number of Patents: 002  
Patent Family:

Patent No	Kind	Date	Applicat No	Kind	Date	Week
WO 200014455	A1	20000316	WO 99US20220	A	19990902	200022 B
AU 9957036	A	20000327	AU 9957036	A	19990902	200032

Priority Applications (No Type Date): US 98148029 A 19980903

Patent Details:

Patent No Kind Lan Pg Main IPC Filing Notes

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Designated States (National): AL AM AT AU AZ BA BB BG BR BY CA CH CN CU  
CZ DE DK EE ES FI GB GD GE GH GM HR HU ID IL IS JP KE KG KP KR KZ LC LK  
LR LS LT LU LV MD MG MK MN MW MX NO NZ PL PT RO RU SD SE SG SI SK SL TJ  
TM TR TT UA UG US UZ VN YU ZW

Designated States (Regional): AT BE CH CY DE DK EA ES FI FR GB GH GM GR  
IE IT KE LS LU MC MW NL OA PT SD SE SL SZ UG ZW

AU 9957036 A F24H-003/00 Based on patent WO 200014455

Inventor: GASLJEVIC K ...

... MATTHYS E F  
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Set	Items	Description
S1	2	AU=(MATTHYS E? OR MATTHYS, E? OR GASLIEVIC K? OR GASLJEVIC K? OR GASLJIEVIC K? OR GASLIEVIC, K? OR GASLJEVIC, K? OR GASLJIEVIC, K?)
S2	0	ERIC(2W)MATTHYS OR (KAZIMIR OR CASIMIR) (2W) (GASLIEVIC OR GASLJEVIC OR GASLJIEVIC)
S3	0	AU=(BEWERSDORFF H? OR BEWERSDORFF, H?)
S4	2	H?(2W)BEWERSDORFF
S5	0	AU=(ZAKIN J? OR ZAKIN, J?)
S6	0	JACQUES(2W)ZAKIN
S7	16525	(DRAG? OR FRICTION? OR (HEAT? OR THERM?) (2N)EXCHANG?) AND - (SURFACTANT? OR SURFACE()ACTIVE)
S8	52042	IC=(F24H? OR C10M? OR C09K? OR F28F? OR F28D? OR C11D?)
S9	4	S1 OR S4
S10	4	IDPAT (sorted in duplicate/non-duplicate order)

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File 348:EUROPEAN PATENTS 1978-2004/May W01

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File 349:PCT FULLTEXT 1979-2002/UB=20040513,UT=20040506

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10/3,K/3 (Item 3 from file: 348)  
DIALOG(R) File 348:EUROPEAN PATENTS  
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01147042

METHODS TO CONTROL HEAT TRANSFER IN FLUIDS CONTAINING DRAG-REDUCING  
ADDITIVES

PROCEDES DE COMMANDE DE TRANSFERT DE CHALEUR DANS DES FLUIDES CONTENANT DES  
ADDITIFS REDUCTEURS DE PERTE DE POUSSEE

PATENT ASSIGNEE:

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designated States: all)

INVENTOR:

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MATTHYS, Eric, F. , 1263 San Antonio Creek Road, Santa Barbara, CA 93111  
, (US

PATENT (CC, No, Kind, Date):

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APPLICATION (CC, No, Date): EP 99944066 990902; WO 99US20220 990902

PRIORITY (CC, No, Date): US 148029 980903

DESIGNATED STATES: AT; BE; CH; CY; DE; DK; ES; FI; FR; GB; GR; IE; IT; LI;  
LU; MC; NL; PT; SE

INTERNATIONAL PATENT CLASS: F24H-003/00; C10M-105/08; C09K-005/00

LANGUAGE (Publication,Procedural,Application): English; English; English

INVENTOR:

GASLJEVIC, Kazimir ...

...US)

MATTHYS, Eric, F ...

10/3,K/4 (Item 4 from file: 349)  
DIALOG(R)File 349:PCT FULLTEXT  
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00551082 \*\*Image available\*\*

METHODS TO CONTROL HEAT TRANSFER IN FLUIDS CONTAINING DRAG-REDUCING  
ADDITIVES

PROCEDES DE COMMANDE DE TRANSFERT DE CHALEUR DANS DES FLUIDES CONTENANT DES  
ADDITIFS REDUCTEURS DE PERTE DE POUSSEE

Patent Applicant/Assignee:

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Inventor(s):

GASLJEVIC Kazimir ,  
MATTHYS Eric F

Patent and Priority Information (Country, Number, Date):

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Priority Application: US 98148029 19980903

Designated States: AL AM AT AU AZ BA BB BG BR BY CA CH CN CU CZ DE DK EE ES

FI GB GD GE GH GM HR HU ID IL IS JP KE KG KP KR KZ LC LK LR LS LT LU LV

MD MG MK MN MW MX NO NZ PL PT RO RU SD SE SG SI SK SL TJ TM TR TT UA UG

US UZ VN YU ZW GH GM KE LS MW SD SL SZ UG ZW AM AZ BY KG KZ MD RU TJ TM

AT BE CH CY DE DK ES FI FR GB GR IE IT LU MC NL PT SE BF BJ CF CG CI CM

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Inventor(s):

GASLJEVIC Kazimir ...

... MATTHYS Eric F

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Set	Items	Description
S1	245	AU=(MATTHYS E? OR MATTHYS, E? OR GASLIEVIC K? OR GASLJEVIC K? OR GASLJIEVIC K? OR GASLIEVIC, K? OR GASLJEVIC, K? OR GASLJIEVIC, K?)
S2	0	ERIC(2W)MATTHYS OR (KAZIMIR OR CASIMIR) (2W) (GASLIEVIC OR GASLJEVIC OR GASLJIEVIC)
S3	57	AU=(BEWERSDORFF H? OR BEWERSDORFF, H?)
S4	0	H?(2W)BEWERSDORFF
S5	177	AU=(ZAKIN J? OR ZAKIN, J?)
S6	1	JACQUES(2W)ZAKIN
S7	2322	(DRAG? OR FRICTION? OR (HEAT? OR THERM?) (2N)EXCHANG?) AND - (SURFACTANT? OR SURFACE()ACTIVE)
S8	144	S1:S6 AND S7
S9	95	S8 AND PY<2000
S10	58	RD (unique items)

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File 94:JICST-EPlus 1985-2004/Apr W4  
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(c) 2004 RAPRA Technology Ltd

File 25:Weldasearch 1962-2004/Dec  
(c) 2004 TWI Ltd

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10/3,K/1 (Item 1 from file: 95)  
DIALOG(R)File 95:TEME-Technology & Management  
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01405680 20000108304

**Coupling between heat and momentum transfer mechanisms for drag -reducing polymer and surfactant solutions**

Aguilar, G; Gasljevic, K ; Matthys, EF

Univ. of California, Santa Barbara, USA

Transactions of the ASME, Journal of Heat Transfer, v121, n4, pp796-802, 1999

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Record type: Abstract

ISSN: 0022-1481

**Coupling between heat and momentum transfer mechanisms for drag -reducing polymer and surfactant solutions**

Aguilar, G; Gasljevic, K ; Matthys, EF

1999

**ABSTRACT:**

**Drag** -reducing solutions exhibit simultaneous **friction** and heat transfer reductions, yet it has been widely believed that there is no direct...

...two. In this work, we have conducted study to reexamine this issue, using measurements of **friction** and heat transfer over a range of flow conditions from onset to asymptotic, various pipe diameters, and several polymer and **surfactant** solutions. Contrary to some earlier suggestions, our tests show that no decoupling of the momentum and heat transfer mechanisms was seen at the onset of **drag** reduction, nor upon departure from the asymptotes, but rather that the **friction** and heat transfer reductions change simultaneously in those regions. For asymptotic **surfactant** and polymer solutions, the ratio of heat transfer and **drag** reductions was seen to be constant over a large range of Reynolds numbers, if modified...

...reduction parameters are used. In the nonasymptotic region, however, the ratio of heat transfer to **drag** reductions is higher and is a function of the reduction level, but is approximately the same for polymer and **surfactant** solutions. This variation is consistent with the concept of a direct coupling through a nonunity...

...measurements of temperature and velocity profiles. We also saw that our diameter scaling technique for **friction** applies equally well to heat transfer. These findings allow us to predict directly the heat transfer from **friction** measurements or vice versa for these **drag** -reducing fluids, and also suggest that a strong coupling exists between the heat and momentum...

DESCRIPTORS: **SURFACE ACTIVE AGENTS**; HEAT TRANSMISSION; POLYMERS; PRANDTL NUMBER; SURFACE STRUCTURE

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10/3,K/2 (Item 2 from file: 95)  
DIALOG(R)File 95:TEME-Technology & Management  
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01139841 M97091286670

**Experimental investigation of thermal and hydrodynamic development regions for drag -reducing surfactant solutions**

(Experimentelle Untersuchung der thermischen und hydrodynamischen

Entwicklung von Rohrstroemungen mit widerstandsreduzierenden  
oberflaechenaktiven Zusaetzen)

Gasljevic, K ; Matthys, EF

Univ. of California, Santa Barbara, USA

Transactions of the ASME, Journal of Heat Transfer, v119, n1, pp80-88,  
1997

Document type: journal article Language: English

Record type: Abstract

ISSN: 0022-1481

**Experimental investigation of thermal and hydrodynamic development regions  
for drag -reducing surfactant solutions**

Gasljevic, K ; Matthys, EF

1997

ABSTRACT:

The reductions in **friction** and heat transfer exhibited by a **surfactant** solution in the entry region of a circular pipe were measured and analyzed, with special attention paid to the relationship between the local heat transfer and **friction** . Two entrance configurations were used, a cone contraction and wire mesh plugs used as a...

...temperature profile with hydrodynamically predeveloped flow were studied. Interestingly, the focal heat transfer measurements for **surfactant** solutions matched very well a correlation developed for Polymer solutions, but for surfactants the development of the heat transfer and velocity profiles appear coupled unlike what is thought...

DESCRIPTORS: DETERGENT; PIPE FLOW; HEAT TRANSMISSION; HEAT DISTRIBUTION; VELOCITY DISTRIBUTION; FLOW VELOCITY; POLYMERS; COEFFICIENT OF **FRICITION** ; NUSSELT NUMBER; CONICITY; WIRE LATTICE; EXPERIMENTAL STUDY

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10/3,K/3 (Item 1 from file: 99)

DIALOG(R)File 99:Wilson Appl. Sci & Tech Abs

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1616437 H.W. WILSON RECORD NUMBER: BAST98009667

**Differences in the flow behaviors of polymeric and cationic surfactant  
drag -reducing additives**

Myska, Jiri; Zakin, Jacques L

Industrial & Engineering Chemistry Research v. 36 (Dec. '97) p. 5483-7

DOCUMENT TYPE: Feature Article ISSN: 0888-5885

**Differences in the flow behaviors of polymeric and cationic surfactant  
drag -reducing additives**

Zakin, Jacques L

ABSTRACT: Research on cationic **surfactant drag** -reducing additives has grown in recent years because of their repairability after shear degradation, making...

...and district cooling systems. Substantial differences between their flow behaviors and those of high-polymer, **drag** -reducing additives have been found. These include the influence of preshearing, the effect of mechanical shear on degradation, the influence of tube diameter, maximum **drag** -reduction effectiveness, and the shape of their mean velocity profiles. Examples of these different flow behaviors are described. The differences suggest that the mechanisms for causing **drag** reduction may be different for the two types of additives. Copyright 1997, American Chemical Society.

DESCRIPTORS: ...Cationic surfactants ; ...

... Drag reduction;  
1997

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10/3,K/4 (Item 2 from file: 99)  
DIALOG(R)File 99:Wilson Appl. Sci & Tech Abs  
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1448059 H.W. WILSON RECORD NUMBER: BAST97005132  
**New limiting drag reduction and velocity profile asymptotes for nonpolymeric additives systems**  
Zakin, Jacques L ; Myska, Jiri; Chara, Zdenek  
AIChE Journal v. 42 (Dec. '96) p. 3544-6  
DOCUMENT TYPE: Feature Article ISSN: 0001-1541

**New limiting drag reduction and velocity profile asymptotes for nonpolymeric additives systems**  
Zakin, Jacques L ;

ABSTRACT: The authors showed that equations proposed by Virk et al. for the limiting maximum **drag** reduction asymptote for high polymers and for an elastic sublayer velocity profile limit are not applicable to aqueous **surfactant** and aluminum disoap in hydrocarbon systems. New, applicable, limiting equations were developed by the authors. It was inferred that the mechanism for high polymer **drag** reduction differs from that for micellar systems.

DESCRIPTORS: ... Surfactants ; ...  
... Drag reduction;  
1996

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10/3,K/5 (Item 1 from file: 35)  
DIALOG(R)File 35:Dissertation Abs Online  
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01451929 ORDER NO: AADAA-I9542028  
**AN EXPERIMENTAL INVESTIGATION OF DRAG REDUCTION BY SURFACTANT SOLUTIONS AND OF ITS IMPLEMENTATION IN HYDRONIC SYSTEMS (TURBULENT FLOW, HEAT TRANSFER)**

Author: GASLJEVIC, KAZIMIR  
Degree: PH.D.  
Year: 1995  
Corporate Source/Institution: UNIVERSITY OF CALIFORNIA, SANTA BARBARA (0035)  
Source: VOLUME 56/08-B OF DISSERTATION ABSTRACTS INTERNATIONAL.  
PAGE 4539. 389 PAGES

**AN EXPERIMENTAL INVESTIGATION OF DRAG REDUCTION BY SURFACTANT SOLUTIONS AND OF ITS IMPLEMENTATION IN HYDRONIC SYSTEMS (TURBULENT FLOW, HEAT TRANSFER)**

Author: GASLJEVIC, KAZIMIR  
Year: 1995

This is a study of fluid mechanics and heat transfer of **surfactant** water solutions, which exhibit **drag** reduction in the turbulent flow (when compared to pure water). The stress is placed on those aspects of flow and

heat transfer behavior of **drag** reducing solutions which are relevant for application in closed circulation loops (for the purpose of...

...in buildings. Most of the tests are done with the same solution of the cationic **surfactant** ETHOQUAD T13 in concentration of 2300 ppm, plus 2000 ppm sodium salicylate as counter ion...

...to the room temperature.

The following are the main problems studied: diameter effect, fluid characterization ( **drag** reducing ability and capillary viscometry), different types of degradation (permanent and temporary), thermal and hydrodynamic flow development in the entry region, flow through an elbow, heat transfer in different **heat exchangers**, **heat** transfer enhancement, effect on pumps and valves, corrosion of standard building materials when exposed to the **surfactant** solution and disposal of used **surfactant** solution. We feel that all of the problems studied are understood and solved satisfactorily so...

...be done. Despite encouraging results with inserts for heat transfer enhancement, reduced heat transfer in **heat exchangers** can be singled out as the most serious problem for successful application in circulation loops...

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10/3,K/6 (Item 1 from file: 2)  
DIALOG(R)File 2:INSPEC  
(c) 2004 Institution of Electrical Engineers. All rts. reserv.

6257926 INSPEC Abstract Number: A1999-13-6810-007

Title: **Effect of variations in counterion to surfactant ratio on rheology and microstructures of drag reducing cationic surfactant systems**

Author(s): Lu, B.; Zakin, J.L.; Zheng, Y.; Davis, H.T.; Scriven, L.E.; Talmon, Y.

Author Affiliation: Dept. of Chem. Eng., Ohio State Univ., Columbus, OH, USA

Journal: Rheologica Acta vol.37, no.6 p.528-48

Publisher: Dr. Dietrich Steinkopff Verlag,

Publication Date: Dec. 1998 Country of Publication: Germany

CODEN: RHEAAK ISSN: 0035-4511

SICI: 0035-4511(199812)37:6L:528:EVCS;1-F

Material Identity Number: R029-1999-002

Language: English

Subfile: A

Copyright 1999, FIZ Karlsruhe

Title: **Effect of variations in counterion to surfactant ratio on rheology and microstructures of drag reducing cationic surfactant systems**

Author(s): Lu, B.; Zakin, J.L.; Zheng, Y.; Davis, H.T.; Scriven, L.E.; Talmon, Y.

Abstract: Rheology, **drag** reduction and cryo-TEM experiments were performed on Arquad 16-50/NaSal and ethoquad O/12/NaSal **surfactant** systems at different counterion-to-**surfactant** ratios and at constant low **surfactant** concentrations, 5 mM, appropriate for **drag** reduction. The molar ratio of counterion-to-**surfactant** was varied from 0.6 to 2.5. All the **surfactant** systems described here are viscoelastic and **drag** reducing. The viscoelasticity and **drag** reducing effectiveness increase with increase in counterion/**surfactant** ratio. Network are present in the solutions with high ratio, and they are viscoelastic. However...

... which form entanglement networks, and show that the micellar network becomes denser with increasing counterion/ **surfactant** ratio in one **surfactant** series. Both increase in the counterion/ **surfactant** ratio and increase in the shear rate result in shorter relaxation times. For some of ...

...Descriptors: **drag** reduction...

... **surfactants** ;

...Identifiers: **surfactant** ratio...

... **drag** reduction...

...cationic **surfactants** ;  
1998

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10/3,K/7 (Item 2 from file: 2)

DIALOG(R)File 2:INSPEC

(c) 2004 Institution of Electrical Engineers. All rts. reserv.

5867443 INSPEC Abstract Number: A9809-8270-006

**Title: Micellar size of drag reducing cationic surfactants**

Author(s): Myska, J.; Stepanek, P.; **Zakin, J.L.**

Author Affiliation: Inst. of Hydrodynamics, Prague, Czech Republic

Journal: Colloid & Polymer Science vol.275, no.3 p.254-62

Publisher: Dr. Dietrich Steinkopff Verlag,

Publication Date: March 1997 Country of Publication: Germany

CODEN: CPMSB6 ISSN: 0303-402X

SICI: 0303-402X(199703)275:3L.254:MSDR;1-O

Material Identity Number: M629-98002

Language: English

Subfile: A

Copyright 1998, FIZ Karlsruhe

**Title: Micellar size of drag reducing cationic surfactants**

Author(s): Myska, J.; Stepanek, P.; **Zakin, J.L.**

Abstract: Dynamic light scattering was employed to determine the effects of **surfactant** nature, concentration and counterion ratios, and shear on the hydrodynamic radii of micelles of commercial cationic **surfactants** which are powerful **drag** reducers in turbulent flow at high temperatures. Such **surfactants** are potentially useful for reducing pumping energy losses in district heating and cooling systems.

...Descriptors: **drag** reduction

...Identifiers: cationic **surfactants** ; ...

... **drag** reducers  
1997

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10/3,K/8 (Item 3 from file: 2)

DIALOG(R)File 2:INSPEC

(c) 2004 Institution of Electrical Engineers. All rts. reserv.

5688170 INSPEC Abstract Number: A9720-4660-002

**Title: A non-viscoelastic drag reducing cationic surfactant system**

Author(s): Lu, B.; Li, X.; **Zakin, J.L.** ; Talmon, Y.

Author Affiliation: Dept. of Chem. Eng., Ohio State Univ., Columbus, OH, USA

Journal: Journal of Non-Newtonian Fluid Mechanics vol.71, no.1-2 p.



59-72

Publisher: Elsevier,  
Publication Date: July 1997 Country of Publication: Netherlands  
CODEN: JNFMDI ISSN: 0377-0257  
SICI: 0377-0257(199707)71:1/2L:59:VDRC;1-1  
Material Identity Number: J272-97007  
U.S. Copyright Clearance Center Code: 0377-0257/97/\$17.00  
Language: English  
Subfile: A  
Copyright 1997, IEE

**Title: A non-viscoelastic drag reducing cationic surfactant system**

Author(s): Lu, B.; Li, X.; Zakin, J.L. ; Talmon, Y.

Abstract: The drag reducing cationic surfactant system, Arquad S-50 (5 mM)/sodium salicylate (12.5 mM), was found to have unusual rheological properties. The system is highly drag reducing and birefringent. Cryo-TEM shows a network of thread-like micelles. However, the system...

... be viscoelastic, contradicting the general belief that there is a correlation between viscoelastic properties and drag reduction. On the other hand, the system has high extensional viscosity, with high extensional viscosity-to-shear viscosity ratios. These results indicate surfactant solutions which do not appear to be viscoelastic can be drag reducing, and that extensional viscosity appears to be the key property controlling drag reducing ability.

...Descriptors: drag reduction

Identifiers: nonviscoelastic drag reducing cationic surfactant system

...

... surfactant solutions...

... drag reducing ability  
1997

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10/3,K/9 (Item 4 from file: 2)  
DIALOG(R)File 2:INSPEC  
(c) 2004 Institution of Electrical Engineers. All rts. reserv.

5638319 INSPEC Abstract Number: A9717-4725-005

**Title: Low-speed streaks in drag-reduced turbulent flow**

Author(s): Hetsroni, G.; Zakin, J.L. ; Mosyak, A.

Author Affiliation: Dept. of Mech. Eng., Technion-Israel Inst. of Technol., Haifa, Israel

Journal: Physics of Fluids vol.9, no.8 p.2397-404

Publisher: AIP,

Publication Date: Aug. 1997 Country of Publication: USA

CODEN: PHFLE6 ISSN: 1070-6631

SICI: 1070-6631(199708)9:8L:2397:SSDR;1-7

Material Identity Number: B479-97007

U.S. Copyright Clearance Center Code: 1070-6631/97/9(8)/2397/8/\$10.00

Language: English

Subfile: A

Copyright 1997, IEE

**Title: Low-speed streaks in drag-reduced turbulent flow**

Author(s): Hetsroni, G.; Zakin, J.L. ; Mosyak, A.

Abstract: The effect of a surfactant drag-reducing additive (530 ppm Habon G solution) on the structure of wall turbulence, both in...

... spacing between the thermal streaks. The experiments were carried out

over a broad range of friction velocities, i.e.,  $u_{\text{sub } p}^* = 0.51 - 3.27$  cm/s. With wall shear...

... 85% was achieved in a tube flow, well below the predictions of the Virk maximum drag reduction asymptote proposed for high polymers. The results of spanwise streak spacing indicate that wall shear velocity may be an appropriate parameter for describing nondimensional streak spacing behavior in drag reducing flows. A hypothesis, based on the average spanwise streak spacing  $\lambda_{\text{sup } +}$ , can be...

Descriptors: drag reduction...

...Identifiers: drag -reduced turbulent flow...

... surfactant drag -reducing additive...

... friction velocities...

...Virk maximum drag reduction asymptote...

... drag reducing flows...

... surfactant solution  
1997

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10/3,K/10 (Item 5 from file: 2)

DIALOG(R)File 2:INSPEC

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5549388 INSPEC Abstract Number: A9710-6125-004

Title: Rheological and rheo-optical characterization of shear-induced structure formation in a nonionic drag -reducing surfactant solution

Author(s): Yuntao Hu; Matthys, E.F.

Author Affiliation: Dept. of Mech. Eng., California Univ., Santa Barbara, CA, USA

Journal: Journal of Rheology vol.41, no.1 p.151-66

Publisher: AIP for Soc. Rheology,

Publication Date: Jan.-Feb. 1997 Country of Publication: USA

CODEN: JORHD2 ISSN: 0148-6055

SICI: 0148-6055(199701/02)41:1L:151:RROC;1-8

Material Identity Number: J304-97001

U.S. Copyright Clearance Center Code: 0148-6055/97/41(1)/151/16/\$10.00

Language: English

Subfile: A

Copyright 1997, IEE

Title: Rheological and rheo-optical characterization of shear-induced structure formation in a nonionic drag -reducing surfactant solution

Author(s): Yuntao Hu; Matthys, E.F.

Abstract: We know of only a few rheological studies of nonionic surfactant solutions, and these did not show clear evidence of shear-induced structures (SIS) formation. This paper reports, however, some rheological and rheo-optical results for nonionic surfactant solutions at different concentrations and temperatures that do show clear evidence of such SIS formation...

... very long time (hundreds of seconds). These transient flow results resemble those exhibited by cationic surfactants or associating polymer solutions. The time needed for the viscosity and  $N_{\text{sub } 1}$  to...

... and then decreases. The steady state  $N_{\text{sub } 1}$  and viscosity levels

increase with the **surfactant** concentration. Both the transient and steady state behavior appear rather insensitive to the addition of...

...Identifiers: nonionic **drag** -reducing **surfactant** solution...

... **surfactant** concentration  
1997

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10/3,K/11 (Item 6 from file: 2)  
DIALOG(R)File 2:INSPEC  
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5500651 INSPEC Abstract Number: A9706-4660-007

**Title: The effects of salts on the rheological characteristics of a drag -reducing cationic surfactant solution with shear-induced micellar structures**

Author(s): Hu, Y.; **Matthys, E.F.**

Author Affiliation: Mater. Res. Lab., California Univ., Santa Barbara, CA, USA

Journal: Rheologica Acta vol.35, no.5 p.470-80

Publisher: Dr. Dietrich Steinkopff Verlag,

Publication Date: Sept.-Oct. 1996 Country of Publication: Germany

CODEN: RHEAAK ISSN: 0035-4511

SICI: 0035-4511(199609/10)35:5L.470:ESRC;1-W

Material Identity Number: R029-97001

Language: English

Subfile: A

Copyright 1997, FIZ Karlsruhe

**Title: The effects of salts on the rheological characteristics of a drag -reducing cationic surfactant solution with shear-induced micellar structures**

Author(s): Hu, Y.; **Matthys, E.F.**

...Abstract: effect of the counterion salt sodium salicylate (NaSal) on the transient rheological properties of a **drag** -reducing **surfactant** system tris (2-hydroxyethyl) tallow alkyl ammonium acetate (TTAA) has been studied with both rheometric...

...These rheological results provide us with tools to determine the optimal concentration ratio for practical **drag** reduction applications.

...Descriptors: **drag** reduction

...Identifiers: **drag** reducing **surfactant** solution...

...cationic **surfactant** solution...

... **drag** reduction applications  
1996

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10/3,K/12 (Item 7 from file: 2)  
DIALOG(R)File 2:INSPEC  
(c) 2004 Institution of Electrical Engineers. All rts. reserv.

5419218 INSPEC Abstract Number: A9624-4660-007

**Title: Viscoelasticity of a surfactant and its drag -reducing ability**

Author(s): Myska, J.; **Zakin, J.L.** ; Chara, Z.

Author Affiliation: Inst. of Hydrodynamics, Czechoslovak Acad. of Sci., Prague, Czech Republic

Journal: Applied Scientific Research Conference Title: Appl. Sci. Res. (Netherlands) vol.55, no.4 p.297-310

Publisher: Kluwer Academic Publishers,  
Publication Date: 1995-1996 Country of Publication: Netherlands  
CODEN: ASRHAU ISSN: 0003-6994  
SICI: 0003-6994(1995/1996)55:4L:297:VSDR;1-X  
Material Identity Number: A022-96003  
U.S. Copyright Clearance Center Code: 0003-6994/95-96/\$8.50  
Conference Title: EUROMECH Colloquium 332 - Drag Reduction. 9th European  
Drag Reduction Meeting  
Conference Date: 19-21 April 1995 Conference Location: Ravello, Italy  
Language: English  
Subfile: A  
Copyright 1996, IEE

**Title: Viscoelasticity of a surfactant and its drag -reducing ability**  
**Author(s): Myska, J.; Zakin, J.L. ; Chara, Z.**  
**Abstract:** There is considerable interest in the use of viscoelastic cationic **surfactant** -counterion mixtures in district heating and cooling systems to reduce pressure losses. A recent field...

... showed a 30+% reduction in pumping energy requirements. We have studied a number of commercial **surfactants** and we report here results of rheological, **drag** reduction and turbulence measurements on Arquad 18-50 (octadecyl trimethyl ammonium chloride (AR 18)) with...

... 18 and 4.0 mM NA which is about one third the concentration for excellent **drag** reduction in this **surfactant** 's effective temperature range 30-90 degrees C. Viscosity,  $\eta$  vs. shear rate,  $D$ , first normal stress difference,  $N_1$  vs. shear rate, **drag** reduction (as pressure drop,  $\Delta P/l$ ) vs. average velocity,  $U_{ave}$  in a 39.4 mm tube for AR 18, and turbulence intensity data for three **drag** reducing **surfactants** are reported. Of particular interest are the generally low turbulence intensities in all three directions...

... normal stress differences at 20 degrees C for AR 18, a temperature at which no **drag** reduction occurs with this **surfactant** , indicating that normal stress effects do not correlate directly with **drag** reduction. The effect of time of pumping on increasing **drag** reduction demonstrates that this factor overwhelms the expected increase in **drag** reduction as temperature is raised from 18-19 degrees C to 40.5 degrees C.

Descriptors: **drag** reduction...

Identifiers: viscoelastic cationic **surfactant** -counterion mixtures...

... **drag** reduction  
1995 ; 1996

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10/3,K/13 (Item 8 from file: 2)  
DIALOG(R)File 2:INSPEC  
(c) 2004 Institution of Electrical Engineers. All rts. reserv.

5152073 INSPEC Abstract Number: A9603-4660-010

**Title: Characterization of micellar structure dynamics for a drag -reducing surfactant solution under shear: normal stress studies and flow geometry effects**

**Author(s): Hu Yuntao; Matthys, E.F.**

**Author Affiliation:** Dept. of Mech. Eng., California Univ., Santa Barbara, CA, USA

**Journal:** Rheologica Acta vol.34, no.5 p.450-60

**Publisher:** Dr. Dietrich Steinkopff Verlag,

**Publication Date:** Sept.-Oct. 1995 **Country of Publication:** West Germany

CODEN: RHEAAK ISSN: 0035-4511  
SICI: 0035-4511(199509/10)34:5L:450:CMSD;1-7  
Material Identity Number: R029-95004  
Language: English  
Subfile: A  
Copyright 1996, FIZ Karlsruhe

**Title: Characterization of micellar structure dynamics for a drag-reducing surfactant solution under shear: normal stress studies and flow geometry effects**

Author(s): Hu Yuntao; Matthys, E.F.

Abstract: Some **surfactant** solutions have been observed to exhibit a strong **drag** reduction behavior in turbulent flow. This effect is generally believed to result from the formation...

... and understand better these fluids, we have studied the transient rheological properties of an efficient **drag**-reducing aqueous solution: tris (2-hydroxyethyl) tallowalkyl ammonium acetate (TTAA) with added sodium salicylate (NaSal...

...Descriptors: **drag** ;

...Identifiers: **surfactant** solution...

... **drag** reduction  
1995

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10/3,K/14 (Item 9 from file: 2)

DIALOG(R)File 2:INSPEC

(c) 2004 Institution of Electrical Engineers. All rts. reserv.

4655883 INSPEC Abstract Number: A9411-4660-003

**Title: Measurement of the orientational binding of counterions by nuclear magnetic resonance measurements to predict drag reduction in cationic surfactant micelle solutions**

Author(s): Smith, B.C.; Chou, L.C.; Zakin, J.L.

Author Affiliation: Int. Paper, Mobile, AL, USA

Journal: Journal of Rheology vol.38, no.1 p.73-83

Publication Date: Jan.-Feb. 1994 Country of Publication: USA

CODEN: JORHD2 ISSN: 0148-6055

U.S. Copyright Clearance Center Code: 0148-6055/94/\$4.00

Language: English

Subfile: A

**Title: Measurement of the orientational binding of counterions by nuclear magnetic resonance measurements to predict drag reduction in cationic surfactant micelle solutions**

Author(s): Smith, B.C.; Chou, L.C.; Zakin, J.L.

Abstract: Quaternary ammonium cationic **surfactants** with appropriate counterions are viscoelastic **friction** reducers and can reduce pumping energy requirements, increase water throughput, or reduce pump size or pipeline diameter in closed loop district heating and cooling systems.

**Drag** reduction occurs when rod-like micelles are present. Isomers of ortho-, meta-, and para-hydroxy...

... used to infer which counterions induce rod-like micellar aggregates and the occurrence of viscoelasticity. **Drag** reduction was only observed in the solutions which demonstrated peak broadening. The NMR chemical shift...

... environments can stabilize the micellar interface to facilitate the sphere-to-rod transition and induce **drag** reduction. Thus, FT-NMR peak

broadening and chemical shift data can be used to predict the drag-reducing capability of cationic surfactant-counterion systems.

...Identifiers: drag reduction...

...cationic surfactant micelle solutions...

...viscoelastic friction reducers...

... drag -reducing capability...

...cationic surfactant -counterion systems  
1994

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10/3,K/15 (Item 10 from file: 2)

DIALOG(R)File 2:INSPEC

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4644267 INSPEC Abstract Number: A9410-4725-009

Title: Turbulence measurements of drag reducing surfactant systems

Author(s): Chara, Z.; Zakin, J.L. ; Severa, M.; Myska, J.

Author Affiliation: Inst. of hydrodynamics, Praha, Czech Republic

Journal: Experiments in Fluids vol.16, no.1 p.36-41

Publication Date: Nov. 1993 Country of Publication: West Germany

CODEN: EXFLDU ISSN: 0723-4864

Language: English

Subfile: A

Title: Turbulence measurements of drag reducing surfactant systems

Author(s): Chara, Z.; Zakin, J.L. ; Severa, M.; Myska, J.

...Abstract: intensity in a 39.4 mm diameter tube, the first measurements in three directions on drag reducing surfactant solutions (0.05% and 0.1% Habon G). Drag reduction exceeded the predictions of the Virk maximum drag reduction asymptote and elastic sublayer mean velocity profiles are steeper than the profile proposed by Virk for maximum drag reducing asymptote solutions. Axial turbulence intensities for Habon G solutions are higher than those for...

...Descriptors: drag reduction

...Identifiers: drag reducing surfactant systems...

...Virk maximum drag reduction asymptote  
1993

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10/3,K/16 (Item 11 from file: 2)

DIALOG(R)File 2:INSPEC

(c) 2004 Institution of Electrical Engineers. All rts. reserv.

4468436 INSPEC Abstract Number: A9319-4725F-009

Title: Turbulence structure of dilute polymer and surfactant solutions in artificially roughened pipes

Author(s): Bewersdorff, H.-W. ; Thiel, H.

Author Affiliation: Inst. of Hydromech. & Water Research Manage., Swiss Federal Inst. of Technol., Zurich, Switzerland

Journal: Applied Scientific Research vol.50, no.3-4 p.347-68

Publication Date: May 1993 Country of Publication: Netherlands

CODEN: ASRHAU ISSN: 0003-6994

Conference Title: Sixth European Drag Reduction Meeting

Conference Date: Nov. 1991 Conference Location: Eindhoven, Netherlands

Language: English

Subfile: A

**Title:** Turbulence structure of dilute polymer and surfactant solutions in artificially roughened pipes

**Author(s):** Bewersdorff, H.-W. ; Thiel, H.

**Abstract:** Pressure drop and velocity profile measurements are presented for turbulent flows of drag reducing fluids. The investigation was done in two rough pipes, known as 'k'- and 'd...

... that the hydrodynamic influence of the roughness is restricted to the near-wall region. The drag reducing surfactant solution exhibited a drag reduction in the smooth as well as in the rough pipes which was higher than that given by Virk's maximum drag reduction asymptote. For this solution no influence of the roughness on the turbulence was detected

...

**Descriptors:** drag reduction...

...Identifiers: surfactant solutions...

... drag reducing fluids...

...Virk's maximum drag reduction asymptote  
1993

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10/3,K/17 (Item 12 from file: 2)

DIALOG(R)File 2:INSPEC

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03553466 INSPEC Abstract Number: A90027667

**Title:** SANS- and LS-studies on drag-reducing surfactant solutions

**Author(s):** Bewersdorff, H.W. ; Dohmann, J.; Langowski, J.; Lindner, P.; Maack, A.; Oberthur, R.; Thiel, H.

**Author Affiliation:** Dortmund Univ., West Germany

**Journal:** Physica B vol.156-157 p.508-11

**Publication Date:** Jan.-Feb. 1989 **Country of Publication:** Netherlands

**CODEN:** PHYBE3 **ISSN:** 0921-4526

**U.S. Copyright Clearance Center Code:** 0921-4526/89/\$03.50

**Conference Title:** 4th International Conference on Neutron Scattering (ICNS 88)

**Conference Date:** 12-15 July 1988 **Conference Location:** Grenoble, France

**Language:** English

**Subfile:** A

**Title:** SANS- and LS-studies on drag-reducing surfactant solutions

**Author(s):** Bewersdorff, H.W. ; Dohmann, J.; Langowski, J.; Lindner, P.; Maack, A.; Oberthur, R.; Thiel, H.

**Abstract:** SANS-measurements of dilute surfactant solutions containing rodlike micelles were performed under laminar and turbulent ( drag-reduced) flow conditions in a pipe geometry. Experiments indicate that the increase local stresses in...

**Descriptors:** drag reduction...

...Identifiers: drag-reducing surfactant solutions

1989

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10/3,K/18 (Item 13 from file: 2)

DIALOG(R)File 2:INSPEC

(c) 2004 Institution of Electrical Engineers. All rts. reserv.

02893409 INSPEC Abstract Number: A87069228

**Title:** The conformation of drag reducing micelles from

**small-angle-neutron-scattering experiments**

Author(s): **Bewersdorff, H.-W. ; Frings, B. ; Lindner, P. ; Oberthur, R.C.**  
Author Affiliation: Fachbereich Chemietechnik, Dortmund Univ., West Germany  
Journal: Rheologica Acta vol.25, no.6 p.642-6  
Publication Date: Nov.-Dec. 1986 Country of Publication: West Germany  
CODEN: RHEAAK ISSN: 0035-4511  
Language: English  
Subfile: A

**Title: The conformation of drag reducing micelles from small-angle-neutron-scattering experiments**

Author(s): **Bewersdorff, H.-W. ; Frings, B. ; Lindner, P. ; Oberthur, R.C.**

Abstract: Small-angle-neutron-scattering measurements (SANS) were done with a dilute solution of the **surfactant** n-tetradecyltrimethylammoniumbromide (TTAB) with sodium salicylate (Na Sal) in pipe and channel flow. The solvent...

... was heavy water. The anisotropy observed in the SANS-curves can be related to the **drag** reduction behaviour of the **surfactant** solution. The breakdown of the **drag** reducing properties above the critical wall shear stress is accompanied by a strong decrease in...

...Descriptors: **drag** reduction

...Identifiers: **drag** reducing micelles...

... **surfactant** n-tetradecyltrimethylammoniumbromide  
1986

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10/3,K/19 (Item 14 from file: 2)  
DIALOG(R)File 2:INSPEC  
(c) 2004 Institution of Electrical Engineers. All rts. reserv.

01392471 INSPEC Abstract Number: A79077192

**Title: Transport of oils as oil-in-water emulsions**

Author(s): **Zakin, J.L. ; Pinaire, R. ; Borgmeyer, M.E.**

Author Affiliation: Dept. of Chem. Engng., Univ. of Missouri, Rolla, MO, USA

Journal: Transactions of the ASME. Journal of Fluids Engineering  
vol.101, no.1 p.100-4

Publication Date: March 1979 Country of Publication: USA

CODEN: JFEA4 ISSN: 0098-2202

Language: English

Subfile: A

Author(s): **Zakin, J.L. ; Pinaire, R. ; Borgmeyer, M.E.**

...Abstract: of oil viscosity, temperature and oil concentration on specific energy loss were evaluated. Measured turbulent **friction** factors consistently fell below those predicted by the Dodge and Metzner **friction** factor correlation, probably due to viscoelastic effects of the emulsion. Several polymer and **surfactant** **drag** reducers were tested in these emulsions, and high molecular weight polyacrylamides were found to be...

...Identifiers: turbulent **friction** factors...

... **surfactant** **drag** reducers  
1979

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10/3,K/20 (Item 15 from file: 2)  
DIALOG(R)File 2:INSPEC  
(c) 2004 Institution of Electrical Engineers. All rts. reserv.



00440858 INSPEC Abstract Number: A72071162

**Title:** Non-ionic surfactants as drag reducing additives

**Author(s):** Zakin, J.L. ; Chiang, J.L.

**Author Affiliation:** Univ. Missouri, Rolla, MO, USA

**Journal:** Nature (Physical Science) vol.239, no.89 p.26-8

**Publication Date:** 11 Sept. 1972 **Country of Publication:** UK

**CODEN:** NPSCA6 **ISSN:** 0300-8746

**Language:** English

**Subfile:** A

**Title:** Non-ionic surfactants as drag reducing additives

**Author(s):** Zakin, J.L. ; Chiang, J.L.

**Abstract:** Reports studies of a non-ionic surfactant which is effective as a drag reducing additive, in combination with salts, close to the conservation or precipitation point. The non-ionic surfactant studied was 'Alfonic 1214-60' (Continental Oil Company, Ponca City, Oklahoma), which is a mixture...

**Identifiers:** non ionic surfactants ; ...

... drag reducing additive  
1972

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10/3,K/21 (Item 1 from file: 6)

DIALOG(R)File 6:NTIS

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1706069 NTIS Accession Number: DE93002508

**Reduction of pumping energy losses in district heating and cooling systems. Final report**

**Zakin, J. L. ; Christensen, R. N.**

Ohio State Univ., Columbus.

Corp. Source Codes: 005518000; 4898000

Sponsor: Department of Energy, Washington, DC.

Report No.: DOE/CE/26565-T1

Oct 92 11p

Languages: English

Journal Announcement: GRAI9308; ERA9313

Sponsored by Department of Energy, Washington, DC.

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NTIS Prices: PC A03/MF A01

**Zakin, J. L. ; Christensen, R. N.**

This project was designed to find effective surfactant friction reducing additives for use in district heating systems with temperatures of 50 to 90(degrees...

... temperatures of 5 to 15(degrees)C. Heat transfer measurements in conventional shell and tube heat exchangers and in plate heat exchangers were also carried out to see how seriously these surfactant drag reducing additives reduce heat transfer coefficients.

**Descriptors:** District Cooling; \*District Heating; \*Energy Losses; \*Pumping; Additives; Drag ; Friction ; Heat Exchangers ; Surfactant  
sOrder this

10/3,K/22 (Item 1 from file: 8)  
DIALOG(R)File 8:EI Compendex(R)  
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05202928 E.I. No: EIP99014529621

Title: Field test of a drag-reducing surfactant additive in the hydronic cooling system of a building - Phase 2: Heat transfer control

Author: Gasljevic, K. ; Hoyer, K.; Matthys, E.F.

Corporate Source: Univ of California, Santa Barbara, CA, USA

Conference Title: Proceedings of the 1998 ASME International Mechanical Engineering Congress and Exposition

Conference Location: Anaheim, CA, USA Conference Date: 19981115-19981120

E.I. Conference No.: 49454

Source: Heat Transfer Division - 3 American Society of Mechanical Engineers, Heat Transfer Division, (Publication) HTD v 361-3 1998. ASME, Fairfield, NJ, USA. p 255-263

Publication Year: 1998

CODEN: ASMHD8 ISSN: 0272-5673

Language: English

Title: Field test of a drag-reducing surfactant additive in the hydronic cooling system of a building - Phase 2: Heat transfer control

Author: Gasljevic, K. ; Hoyer, K.; Matthys, E.F.

...Abstract: building. This test was the second phase of a study of the possible use of drag-reducing additives in hydronic systems for pumping power reduction. In the first phase of the...

...pumping power savings was achievable in this system, regardless of heat transfer reduction in the heat exchangers. We measured about 30% of pumping power savings. The recent second phase of the field...

...ascertain whether it is possible to control or eliminate the heat transfer reduction in the heat exchangers. This is an important issue because a loss in heat transfer capacity would lead to...

...did indeed show in the second test that the use of an improved non-ionic surfactant did in fact allow us to control fully the heat transfer in the heat exchangers (both evaporator and cooling coils) by means of intentional temporary degradation of the drag-reducing properties of the solution. Even with full elimination of heat transfer reduction, we still

...  
Descriptors: Heat transfer; Air conditioning; Buildings; Heat exchangers ; Energy conservation; Surface active agents; Additives; Drag ; Cooling systems; Thermal load

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10/3,K/23 (Item 2 from file: 8)  
DIALOG(R)File 8:EI Compendex(R)  
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05202855 E.I. No: EIP99014530252

Title: On the relationship between heat transfer and drag reductions for polymer and surfactant solutions

Author: Aguilar, G.; Gasljevic, K. ; Matthys, E.F.

Corporate Source: Univ of California at Santa Barbara, Santa Barbara, CA, USA

Conference Title: Proceedings of the 1998 ASME International Mechanical Engineering Congress and Exposition

Conference Location: Anaheim, CA, USA Conference Date:

19981115-19981120

E.I. Conference No.: 49454

Source: Heat Transfer Division -1 American Society of Mechanical Engineers, Heat Transfer Division, (Publication) HTD v 361-1 1998. ASME, Fairfield, NJ, USA. p 139-144

Publication Year: 1998

CODEN: ASMHD8 ISSN: 0272-5673

Language: English

**Title: On the relationship between heat transfer and drag reductions for polymer and surfactant solutions**

Author: Aguilar, G.; Gasljevic, K. ; Matthys, E.F.

Abstract: Drag-reducing solutions exhibit simultaneous friction and heat transfer reductions, yet it has been widely believed that there is a decoupling...

...flow conditions from onset to asymptotic, pipe diameters, and various fluids ranging from polymer to surfactant solutions. All our data and those of some other investigators were found to be remarkably well correlated by a constant ratio between the heat transfer and drag reductions over the entire range of conditions examined. In addition, this ratio was found to hold even at and near the onset of drag reduction phenomenon, and also upon departure from the asymptotic regime. We have also shown that the onsets for drag and heat transfer reductions are the same, and that degradation or dilution result in simultaneous departure from asymptotic conditions. All these results support the concept that heat transfer and drag are indeed strongly coupled under all conditions investigated. This information should provide new insight into the fundamental mechanisms underlying the relationship between the drag and heat transfer reduction phenomena. In addition, the practical engineering impact of this finding is very significant in that it allows us now to predict directly the heat transfer from friction measurements or vice-versa, for these fluids. (Author abstract) 25 Refs.

Descriptors: Heat transfer; Drag ; Friction ; Pipe flow; Polymers; Surface active agents

Identifiers: Friction coefficient

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10/3,K/24 (Item 3 from file: 8)  
DIALOG(R)File 8:Ei Compendex(R)  
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04934330 E.I. No: EIP98024054539

**Title: Effect of chemical structure on viscoelasticity and extensional viscosity of drag-reducing cationic surfactant solutions**

Author: Lu, B.; Li, X.; Scriven, L.E.; Davis, H.T.; Talmon, Y.; Zakin, J.L.

Corporate Source: Ohio State Univ, Columbus, OH, USA

Source: Langmuir v 14 n 1 Jan 6 1998. p 8-16

Publication Year: 1998

CODEN: LANGD5 ISSN: 0743-7463

Language: English

**Title: Effect of chemical structure on viscoelasticity and extensional viscosity of drag-reducing cationic surfactant solutions**

Author: Lu, B.; Li, X.; Scriven, L.E.; Davis, H.T.; Talmon, Y.; Zakin, J.L.

Abstract: Drag reduction, shear and extensional rheometry, and cryogenic transmission electron microscopy (cryo-TEM) were used to study aqueous solutions of one cationic surfactant, Arquad 16-50 (5 mM), with

three isomeric counterions, 2-, 3-, or 4-Cl-benzoate at 12.5 mM. Each isomer showed different types of rheological and **drag** reduction behavior and different micellar structures. The 4-Cl system showed good **drag** reduction, high apparent extensional viscosity, and a thread-like micellar network, while the 2-Cl system showed no **drag** reduction, low apparent extensional viscosity, and only spherical micelles. The 3-Cl system was **drag** reducing and had high extensional viscosities at 30 degree C. However, at 20 degree C, the 3-Cl solution precipitated at high shear or extensional rates, leading to loss of **drag** reduction and low apparent extensional viscosity. The 3-Cl at 20 degree C showed thread...

...in the aqueous phase and hence only spherical micelles are formed, which leads to no **drag** reduction and very low apparent extensional viscosity. The chlorine groups in the 3-Cl and...

...micelles can form. A schematic micellar phase diagram is proposed to summarize the transformations of **surfactant** molecular aggregates at different temperatures and external forces. (Author abstract) 43 Refs.

Descriptors: **Surface active** agents; Solutions; Structure (composition); Viscoelasticity; Viscosity; **Drag** ; Flow measurement; Transmission electron microscopy; Micelles; Phase diagrams

Identifiers: Extensional viscosity; **Drag** reduction; Rheometry; Cationic **surfactant**

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10/3,K/25 (Item 4 from file: 8)  
DIALOG(R)File 8:EI Compendex(R)  
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04844405 E.I. No: EIP97103863243

Title: **Evaluation of micellar overlapping parameters for a drag-reducing cationic surfactant system: Light scattering and viscometry**

Author: Hu, Yuntao; **Matthys, Eric F.**

Corporate Source: Univ of California, Santa Barbara, CA, USA

Source: Langmuir v 13 n 19 Sep 17 1997. p 4995-5000

Publication Year: 1997

CODEN: LANGD5 ISSN: 0743-7463

Language: English

Title: **Evaluation of micellar overlapping parameters for a drag-reducing cationic surfactant system: Light scattering and viscometry**

Author: Hu, Yuntao; **Matthys, Eric F.**

...Abstract: equilibrium micellar structure in a tris(2-hydroxyethyl)(tallowalkyl)ammonium acetate (TTAA)/sodium salicylate (NaSal) **surfactant** system has been studied using light scattering and low-shear viscometry methods. Scattered light intensity autocorrelation functions were measured and the hydrodynamic correlation lengths were obtained for solutions with **surfactant** concentrations ranging from 1 to 5 mM and NaSal/TTAA ratios from 0.6 to...

...80 degree C. From the temperature dependence of the hydrodynamic correlation length, the concentration, counterion/ **surfactant** ratio, and temperature at which the free micelles begin to overlap were inferred. The overlapping **surfactant** concentration decreases with increasing counterion/ **surfactant** ratio, and the overlapping ratio decreases with increasing **surfactant** concentration. The overlapping temperature increases with increasing **surfactant** concentration and counterion/ **surfactant** ratio. 'Zero shear rate' viscosities of these solutions at 25 degree C were measured to...

Descriptors: Micelles; **Surface active** agents; Light scattering; Viscosity measurement; Ammonium compounds; Sodium compounds; Hydrodynamics;

Thermal effects; Composition effects

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10/3,K/26 (Item 5 from file: 8)  
DIALOG(R)File 8: Ei Compendex(R)  
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04735868 E.I. No: EIP97063702673

Title: On the diameter effect for turbulent flow of drag -reducing surfactant solutions

Author: Gasljevic, K. ; Matthys, E.F.

Corporate Source: Univ of California, Santa Barbara, CA, USA

Conference Title: Proceedings of the 1995 ASME International Mechanical Engineering Congress and Exposition

Conference Location: San Francisco, CA, USA Conference Date: 19951112-19951117

E.I. Conference No.: 44144

Source: Developments and Applications of Non-Newtonian Flows American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 231 1995. ASME, New York, NY, USA. p 237-243

Publication Year: 1995

CODEN: FEDSDL

Language: English

Title: On the diameter effect for turbulent flow of drag -reducing surfactant solutions

Author: Gasljevic, K. ; Matthys, E.F.

Abstract: The friction coefficient was measured for developed flow of a drag -reducing surfactant solution in four tubes of 2 mm, 10 mm, 20 mm, and 52 mm diameter...

...developing a simple empirical method for prediction and correlation of the pipe diameter effect on friction. With the exception of the tube with the smallest diameter (2 mm), we found that the drag reduction level expressed as a function of bulk fluid velocity is approximately independent of the...

...In the supercritical region, on the other hand, where wall shear stress affects significantly the drag -reducing ability of the fluid, the friction velocity may be a better parameter. (Author abstract) 16 Refs.

Descriptors: Turbulent flow; Solutions; Surface active agents; Drag ; Friction ; Shear flow; Shear stress; Mechanical variables measurement

Identifiers: Diameter effect; Drag reducing surfactant solutions; Solvent shear velocity

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10/3,K/27 (Item 6 from file: 8)  
DIALOG(R)File 8: Ei Compendex(R)  
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04661310 E.I. No: EIP97043590833

Title: Field test of a drag -reducing surfactant additive in a hydronic cooling system

Author: Gasljevic, K. ; Matthys, E.F.

Corporate Source: Univ of California, Santa Barbara, CA, USA

Conference Title: Proceedings of the 1996 ASME Fluids Engineering Division Summer Meeting. Part 2 (of 3)

Conference Location: San Diego, CA, USA Conference Date: 19960707-19960711

E.I. Conference No.: 46196

Source: American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 237 n 2 1996. ASME, New York, NY, USA. p 249-260

Publication Year: 1996

CODEN: FEDSDL

Language: English

**Title: Field test of a drag -reducing surfactant additive in a hydronic cooling system**

Author: Gasljevic, K. ; Matthys, E.F.

...Abstract: conducted in a building-size hydronic cooling system to investigate the possible use of a **drag** -reducing **surfactant** additive as an additive leading to pumping power reduction. A thorough analysis of the system...

...achieved at nominal flow rate, in good agreement with pre-test estimates. The level of **drag** reduction in different sections of the system was also measured. A **drag** reduction of 40% was measured in 6inc. elbows, showing that **drag** reduction can be achieved in large fittings. The heat transfer capacity reduction in the chiller...

...in an air cooling coil was found to be 30% and 20%, respectively, whereas the **drag** reduction in these exchangers was 60% and 35% at full load. The system operation remained...

...nor operational problem observed during the test. The results of the test suggest that the **drag** -reducing additive approach is indeed realistic for complex hydronic systems in buildings, an application more...

...systems targeted so far. These results are very encouraging and suggest that the use of **drag** -reducing additives in this type of systems would result in large energy savings if widely...

Descriptors: **Drag** ; Additives; **Surface active** agents; Cooling systems; Heat transfer; Evaporators; **Heat exchangers** ; Energy efficiency

Identifiers: **Drag** reduction; Hydronic cooling system; Pumping power reduction; Flow rate

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10/3,K/28 (Item 7 from file: 8)  
DIALOG(R)File 8:Ei Compendex(R)  
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04661298 E.I. No: EIP97043590821

**Title: Effect of counterion to surfactant ratio on rheology and drag reduction behaviors of cationic surfactant systems**

Author: Lu, Bin; Talmon, Yeshayahu; **Zakin, Jacques L.**

Corporate Source: Ohio State Univ, Columbus, OH, USA

Conference Title: Proceedings of the 1996 ASME Fluids Engineering Division Summer Meeting. Part 2 (of 3)

Conference Location: San Diego, CA, USA Conference Date: 19960707-19960711

E.I. Conference No.: 46196

Source: American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 237 n 2 1996. ASME, New York, NY, USA. p 169-175

Publication Year: 1996

CODEN: FEDSDL

Language: English

**Title: Effect of counterion to surfactant ratio on rheology and drag**

**reduction behaviors of cationic surfactant systems**

Author: Lu, Bin; Talmon, Yeshayahu; **Zakin, Jacques L.**

Abstract: Rheology, **drag** reduction and cryo-TEM experiments were performed on Arquad 16-50 / NaSal and Ethoquad 0/12 /NaSal **surfactant** systems at different counterion-to- **surfactant** ratios and at low **surfactant** concentrations, 5 mM, appropriate for **drag** reduction. The molar ratio of counterion-to- **surfactant** varied from 0.6 to 2.5. All the **surfactant** systems tested in this research are viscoelastic and **drag** reducing. The viscoelasticity and **drag** reducing effectiveness increase with increase in counterion/ **surfactant** ratio. Excess counterion further increases the viscoelasticity and **drag** reducing effectiveness. Cryo-TEM pictures confirm the existence of thread-like micelles which form entanglement...

...certain shear times were observed in some of the systems investigated. Increase in the counterion/ **surfactant** ratio and increase in shear rate decrease shear stress and normal stress relaxation times. (Author...

Descriptors: **Surface active** agents; Rheology; **Drag** ; Ions; Transmission electron microscopy; Low temperature operations; Viscoelasticity; Micelles; Viscosity; Shear stress

Identifiers: Counterion; **Drag** reduction

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10/3,K/29 (Item 8 from file: 8)

DIALOG(R)File 8: Ei Compendex(R)

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04661297 E.I. No: EIP97043590820

**Title: Comparison of flow behaviors of polymeric and cationic surfactant drag reducing additives**

Author: Myska, Jiri; **Zakin, Jacques L.**

Corporate Source: Inst of Hydrodynamics, Prague, Czech

Conference Title: Proceedings of the 1996 ASME Fluids Engineering Division Summer Meeting. Part 2 (of 3)

Conference Location: San Diego, CA, USA Conference Date: 19960707-19960711

E.I. Conference No.: 46196

Source: American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 237 n 2 1996. ASME, New York, NY, USA. p 165-168

Publication Year: 1996

CODEN: FEDSDL

Language: English

**Title: Comparison of flow behaviors of polymeric and cationic surfactant drag reducing additives**

Author: Myska, Jiri; **Zakin, Jacques L.**

...Abstract: differences exist in the flow behaviors of the two main types of additives useful in **drag** reduction: high molecular weight polymers and cationic **surfactants** . These include the influence of preshearing, the effect of mechanical shear on degradation, the influence of tube diameter, maximum **drag** reduction effectiveness, and the shape of the velocity profiles. Examples of these different flow behaviors...

Descriptors: Turbulent flow; Additives; **Drag** ; **Surface active agents** ; **Ions**<sup>P</sup> ; Polymers; Molecular weight; Velocity; Tubes (components); Viscosity

Identifiers: **Drag** reduction; Dilute polymer solutions; Shear induced structures

10/3,K/30 (Item 9 from file: 8)  
DIALOG(R)File 8:Ei Compendex(R)  
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04661279 E.I. No: EIP97043590802

**Title:** Drag reduction and heat transfer of cationic surfactant solutions

**Author:** Pollert, Jaroslav; Komrzy, Petr; Svejksky, Karel; Jun, Jaroslav Pollert; Lu, Bin; **Zakin, Jacques L.**

**Corporate Source:** Czech Technical Univ, Prague, Czech

**Conference Title:** Proceedings of the 1996 ASME Fluids Engineering Division Summer Meeting. Part 2 (of 3)

**Conference Location:** San Diego, CA, USA **Conference Date:** 19960707-19960711

**E.I. Conference No.:** 46196

**Source:** American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 237 n 2 1996. ASME, New York, NY, USA. p 31-36

**Publication Year:** 1996

**CODEN:** FEDSDL

**Language:** English

**Title:** Drag reduction and heat transfer of cationic surfactant solutions

**Author:** Pollert, Jaroslav; Komrzy, Petr; Svejksky, Karel; Jun, Jaroslav Pollert; Lu, Bin; **Zakin, Jacques L.**

**Abstract:** The use of cationic surfactant drag reducing additives in district heating systems is a very promising method to reduce energy and/or capital investment costs. Laboratory and field test experiments were carried out with drag reducing surfactants in water under different flow and temperature controls. Because of the sensitivity of surfactant additives to wall shear stress, the level of drag reduction was strongly dependent on tube diameter, i.e., with increased diameter, drag reduction increased at constant Reynolds number. Overall heat transfer reduction in a plate fin heat exchanger was below 30% for concentrated surfactant solution with smaller reductions when concentration was reduced. This corresponds to about 50% reduction in the heat transfer coefficient of the surfactant solution. Field tests were carried out in a secondary heating system in Kladno-Krochlavy (Czech Republic) with Habon G as the surfactant additive under different flow and temperature conditions. Pumping energy requirements were reduced by up to 40%. Habon G in the secondary system retained its effectiveness as a drag reducing agent for two winter heating seasons. Either because of very hot walls in the heat exchanger or heavy scale in the old tube-tube exchanger, no significant reduction in overall heat...

**Descriptors:** Surface active agents; Drag ; Heat transfer; Additives; Shear stress; Reynolds number; Heat exchangers ; Heat transfer coefficients; Temperature control

**Identifiers:** Drag reduction; Cationic solutions; Tube diameter; Field testing

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10/3,K/31 (Item 10 from file: 8)  
DIALOG(R)File 8:Ei Compendex(R)  
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04661278 E.I. No: EIP97043590801

**Title:** Rheology of drag reducing surfactant solutions

**Author:** Bewersdorff, Hans-Werner

**Corporate Source:** FH Lausitz, Brandenburg, Ger

**Conference Title:** Proceedings of the 1996 ASME Fluids Engineering



Division Summer Meeting. Part 2 (of 3)

Conference Location: San Diego, CA, USA Conference Date:  
19960707-19960711

E.I. Conference No.: 46196

Source: American Society of Mechanical Engineers, Fluids Engineering  
Division (Publication) FED v 237 n 2 1996. ASME, New York, NY, USA. p 25-29  
Publication Year: 1996

CODEN: FEDSDL

Language: English

**Title: Rheology of drag reducing surfactant solutions**

**Author: Bewersdorff, Hans-Werner**

**Abstract:** In shear flows of drag reducing dilute surfactant solutions, which contain rod-like micelles, a shear thickening occurs when a certain critical shear...

...geometry as well as on the geometrical dimensions of the viscometer. In the SIS these surfactant solutions exhibit a time dependent flow behaviour. For the build-up and the destruction of...

**Descriptors:** Surface active agents; Rheology; Drag ; Shear flow; Viscoelasticity; Stresses; Micelles; Viscometers

**Identifiers:** Drag reducing solutions; Shear thickening; Shear induced state; Critical shear rate

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10/3,K/32 (Item 11 from file: 8)

DIALOG(R)File 8: Ei Compendex(R)

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04612227 E.I. No: EIP97023513531

**Title: Rheological and rheo-optical characterization of shear-induced structure formation in a nonionic drag-reducing surfactant solution**

**Author:** Hu, Yuntao; Matthys, Eric F.

**Corporate Source:** Univ of California, Santa Barbara, CA, USA

**Source:** Journal of Rheology v 41 n 1 Jan-Feb 1997. p 151-166

**Publication Year:** 1997

**CODEN:** JORHD2 **ISSN:** 0148-6055

**Language:** English

**Title: Rheological and rheo-optical characterization of shear-induced structure formation in a nonionic drag-reducing surfactant solution**

**Author:** Hu, Yuntao; Matthys, Eric F.

**Abstract:** We know of only a few rheological studies of nonionic surfactant solutions, and these did not show clear evidence of shear-induced structures (SIS) formation. This paper reports, however, some rheological and rheo-optical results for nonionic surfactant solutions at different concentrations and temperatures that do show clear evidence of such SIS formation...

...very long time (hundreds of seconds). These transient flow results resemble those exhibited by cationic surfactants or associating polymer solutions. The time needed for the viscosity and N//1 to reach...

...point, and then decreases. The steady state N//1 and viscosity levels increase with the surfactant concentration. Both the transient and steady state behavior appear rather insensitive to the addition of...

**Descriptors:** Rheology; Optical properties; Surface active agents; Polymers; Shear flow; Drag ; Viscosity; Birefringence; Temperature

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10/3,K/33 (Item 12 from file: 8)

DIALOG(R)File 8:EI Compendex(R)  
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04080787 E.I. No: EIP95022569369

**Title: Hydrodynamic and thermal field development in the pipe entry region for turbulent flow of drag -reducing surfactant solutions**

Author: **Gasljevic, K. ; Matthys, E.F.**

Corporate Source: Univ of California, Santa Barbara, CA, USA

Conference Title: Proceedings of the 1994 International Mechanical Engineering Congress and Exposition

Conference Location: Chicago, IL, USA Conference Date: 19941106-19941111

E.I. Conference No.: 42353

Source: Developments in Non-Newtonian Flows American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 206 1994. ASME, New York, NY, USA. p 51-61

Publication Year: 1994

CODEN: FEDSDL

Language: English

**Title: Hydrodynamic and thermal field development in the pipe entry region for turbulent flow of drag -reducing surfactant solutions**

Author: **Gasljevic, K. ; Matthys, E.F.**

Abstract: The drag and heat transfer reductions induced by a surfactant solution in the entry region of a circular pipe were measured and analyzed, with special attention paid to the relationship between the local heat transfer and friction. Two entrance configurations were used: a cone contraction and a wire mesh plug used as...

...also measured. A stronger coupling between the hydrodynamic and thermal field developments was observed for surfactant solutions than is generally believed to be the case for polymer solutions. (Author abstract) 13...

Descriptors: Turbulent flow; Hydrodynamics; Pipe flow; Heat transfer; Drag ; Surface active agents ; Fricti on^Energ ; Energy dissipation; Temperature measurement; Velocity measurement

Identifiers: Drag reducing surfactant solutions; Temperature profiles ; Velocity profiles; Flow reorganization effects

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10/3,K/34 (Item 13 from file: 8)

DIALOG(R)File 8:EI Compendex(R)  
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03802349 E.I. No: EIP94021214339

**Title: Effect of drag -reducing surfactant additives on heat exchangers**

Author: **Gasljevic, K. ; Nan, X. ; Matthys, E.F.**

Corporate Source: Univ of California, Santa Barbara, CA, USA

Conference Title: Proceedings of the 1993 ASME Winter Annual Meeting

Conference Location: New Orleans, LA, USA Conference Date: 19931128-19931203

E.I. Conference No.: 19921

Source: Developments in Non - Newtonian Flows American Society of Mechanical Engineers, Applied Mechanics Division, AMD v 175 1993. Publ by ASME, New York, NY, USA. p 101-108

Publication Year: 1993

CODEN: AMDVAS ISSN: 0160-8835 ISBN: 0-7918-1038-0

Language: English

**Title:** Effect of drag -reducing surfactant additives on heat exchangers

**Author:** Gasljevic, K. ; Nan, X.; Matthys, E.F.

**Abstract:** We are presently conducting a study to investigate the possible implementation of drag -reducing additives in hydronic cooling and heating systems in buildings. We have shown that large reductions in friction are achievable, and one of the main remaining issues is therefore the performance of the heat exchangers running these solutions. In this regard, the performance of a plate heat exchanger, a shell-and-tube heat exchanger and a finned tube heat exchanger operating with drag -reducing surfactant solutions was investigated. The test fluid is a solution of 2300 ppm of Ethoquad T...

...flow velocities between 0.2 to 3 m/s, and were compared with results for heat exchangers running tap water. The plate liquid/liquid heat exchanger showed small reductions in pressure loss and heat transfer; the shell-and-tube liquid/liquid heat exchanger showed a much larger heat transfer reduction and a smaller pressure loss reduction; whereas the finned tube heat exchanger showed no significant overall reduction. These results suggest that the heat transfer and friction characteristics are greatly dependent on geometry and flow conditions and could therefore be controlled. It is thus reasonable to expect that an overall high drag reduction in the system could be achieved without sacrificing too much of the heat exchanger performance. The effect of the pipe diameter on the drag reduction of surfactant solutions is also discussed in this paper in the context of heat exchanger analysis. (Author abstract) 11 Refs.

**Descriptors:** Heat exchangers ; Surface active agents; Additives; Drag ; Heat transfer; Temperature measurement; Pressure measurement; Friction ; Fins ( heat exchange )

**Identifiers:** Drag reducing surfactant additives; Plate liquid/liquid heat exchangers ; Shell and tube liquid/liquid heat exchangers ; Pipe diameter

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10/3,K/35 (Item 14 from file: 8)  
DIALOG(R)File 8: Ei Compendex(R)  
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03783499 E.I. No: EIP94011186789

**Title:** On saving pumping power in hydronic thermal distribution systems through the use of drag -reducing additives

**Author:** Gasljevic, K. ; Matthys, E.F.

**Corporate Source:** Univ of California, Santa Barbara, CA, USA

**Source:** Energy and Buildings v 20 n 1 1993. p 45-56

**Publication Year:** 1993

**CODEN:** ENEBDR **ISSN:** 0378-7788

**Language:** English

**Title:** On saving pumping power in hydronic thermal distribution systems through the use of drag -reducing additives

**Author:** Gasljevic, K. ; Matthys, E.F.

**Abstract:** A feasibility study has been conducted to determine whether surfactant drag -reducing additives might be used in hydronic heating and cooling systems for buildings in order...

...additives and system characteristics was undertaken in this context. The question of the level of drag reduction and degradation in - and downstream of - discrete components such as fittings and valves was also investigated, together with the question of possible heat transfer

reduction in **heat exchangers** . Preliminary experimental results indicate that pumps, valves, and fittings will not introduce serious difficulties, and...

...of the additives are made. This analysis leads us to believe that the use of **surfactant drag** -reducing additives in hydronic systems could be implemented at small cost, and would lead to...

Descriptors: Climate control; Buildings; Space heating; Air conditioning; **Heat exchangers** ; **Heat** transfer; **Surface active agents**; Additives; **Drag** ; Energy conservation

Identifiers: Hydronic thermal distribution systems; **Drag** reducing additives; Pumping power

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10/3,K/36 (Item 15 from file: 8)  
DIALOG(R)File 8:EI Compendex(R)  
(c) 2004 Elsevier Eng. Info. Inc. All rts. reserv.

03592633 E.I. Monthly No: EIM9304-023402

**Title: Effect of drag -reducing surfactant solutions on centrifugal pumps performance.**

Author: **Gasljevic, K. ; Matthys, E. F.**

Corporate Source: Univ of California, Santa Barbara, CA, USA

Conference Title: Winter Annual Meeting of the American Society of Mechanical Engineers

Conference Location: Anaheim, CA, USA Conference Date: 19921108

E.I. Conference No.: 17663

Source: Recent Advances in Non-Newtonian Flows American Society of Mechanical Engineers, Applied Mechanics Division, AMD v 153. Publ by ASME, New York, NY, USA. p 49-56

Publication Year: 1992

CODEN: AMDVAS ISSN: 0160-8835 ISBN: 0-7918-1121-2

Language: English

**Title: Effect of drag -reducing surfactant solutions on centrifugal pumps performance.**

Author: **Gasljevic, K. ; Matthys, E. F.**

...Abstract: assessing the potential savings in pumping energy that could be achieved through the use of **surfactant** additives in hydronic thermal distribution systems. It has been shown that **surfactant** solutions are capable of fully recovering their **drag** reduction potential in a relatively short time after being subjected to degradation by high shear...

...The measurements described here were conducted to explore the general features of the flow of **surfactant** solutions through centrifugal pumps, with the purpose of determining (i) the effect of these additives on the pump performance characteristics, and (ii) the effect of the pump itself on the **drag** reduction effectiveness of these fluids. Two typical centrifugal pumps were tested using two different **surfactant** concentrations. It was concluded (i) that the pump flow/head characteristics are unchanged, that the...

...be decreased by up to about 10 percent and (ii) that full recovery of the **drag** reduction effectiveness of the fluid is achieved within a relatively short distance downstream of the...

Descriptors: NON NEWTONIAN FLOW; **DRAG** ; CAVITATION; SOLUTIONS; **SURFACE ACTIVE AGENTS**; DEGRADATION; SHEAR STRESS

Identifiers: **DRAG** REDUCING **SURFACTANT** SOLUTIONS; HYDRONIC THERMAL DISTRIBUTION SYSTEMS

10/3,K/37 (Item 16 from file: 8)  
DIALOG(R)File 8: Ei Compendex(R)  
(c) 2004 Elsevier Eng. Info. Inc. All rts. reserv.

03431220 E.I. Monthly No: EIM9205-025806

Title: Feasibility study of the use of drag -reducing additives to reduce pumping power in hydronic thermal distribution systems.

Author: Gasljevic, K. ; Matthys, E. F.

Corporate Source: Univ of California, Santa Barbara, CA, USA

Conference Title: Winter Annual Meeting of the American Society of Mechanical Engineers

Conference Location: Atlanta, GA, USA Conference Date: 19911201

E.I. Conference No.: 15922

Source: Industrial Applications of Fluid Mechanics - 1991 American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 132. Publ by ASME, New York, NY, USA. p 57-65

Publication Year: 1991

CODEN: FEDSDL ISBN: 0-7918-0888-2

Language: English

Title: Feasibility study of the use of drag -reducing additives to reduce pumping power in hydronic thermal distribution systems.

Author: Gasljevic, K. ; Matthys, E. F.

Abstract: We have conducted a study to determine whether surfactant drag -reducing additives might be used in hydronic heating and cooling systems for buildings in order...

...A matching analysis of the additives and the system characteristics was undertaken. The question of drag reduction in components such as fittings and valves was also investigated, together with the issue of possible heat transfer reduction in heat exchangers. Estimates were obtained to determine the potential energy and cost savings that could be achieved...

...of the additives are made. This analysis leads us to believe that the use of surfactant drag -reducing additives in hydronic systems could be implemented at small cost and would lead to...

...Descriptors: Friction ; FLOW OF FLUIDS...

... Drag ; HEATING

Identifiers: DRAG REDUCTION; ADDITIVES; PUMPING POWER; HYDRONIC HEATING AND COOLING

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10/3,K/38 (Item 17 from file: 8)  
DIALOG(R)File 8: Ei Compendex(R)  
(c) 2004 Elsevier Eng. Info. Inc. All rts. reserv.

02707668 E.I. Monthly No: EI8902011064

Title: Behaviour of drag -reducing cationic surfactant solutions.

Author: Bewersdorff, H. -W. ; Ohlendorf, D.

Corporate Source: Univ Dortmund, Dortmund, West Ger

Source: Colloid and Polymer Science v 266 n 10 Oct 1988 p 941-953

Publication Year: 1988

CODEN: CPMSB6 ISSN: 0303-402X

Language: English

Title: Behaviour of drag -reducing cationic surfactant solutions.

Author: Bewersdorff, H. -W. ; Ohlendorf, D.

Abstract: The behavior of two types of drag reducing surfactant

solutions was studied in turbulent flows in pipes of different diameters. The investigated **surfactant** systems contained rod-like micelles; they consisted of equimolar mixtures of n-tetradecyltrimethylammonium bromide, n ...

...a laser-Doppler anemometer in a 50 mm pipe. In the turbulent flow regime both **surfactant** solutions exhibited characteristic flow regimes. These flow regimes can be influenced by changing the amount of excess salt, the **surfactant** concentration, or the temperature. The shape of the turbulent velocity profile depends on the flow...

...velocity profiles similar to those observed for dilute polymer solutions are found, whereas at maximum **drag** reduction conditions more 'S-shaped' profiles that show deviations from a logarithmic profile occur. An attempt is made to explain the **drag** reduction by rod-like micelles by combining the results of the rheological and the turbulence...

...Descriptors: Optimization; **SURFACE ACTIVE AGENTS**...

Identifiers: **TURBULENT FLOW DRAG REDUCTION; DRAG -REDUCING SURFACTANT ADDITIVES; SURFACTANT MICELLES; LASER DOPPLER ANEMOMETRY**

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10/3,K/39 (Item 18 from file: 8)  
DIALOG(R)File 8: Ei Compendex(R)  
(c) 2004 Elsevier Eng. Info. Inc. All rts. reserv.

02274389 E.I. Monthly No: EIM8709-062089

Title: **INFLUENCE OF DRAG REDUCING SURFACTANTS ON THE STRUCTURE OF TURBULENCE IN PIPE FLOWS.**

Author: **Bewersdorff, H. W. ; Ohlendorf, D.**

Corporate Source: Univ of Dortmund, Dortmund, West Ger

Conference Title: Fifth Symposium on Turbulent Shear Flows.

Conference Location: Ithaca, NY, USA Conference Date: 19850807

E.I. Conference No.: 10122

Source: p 9. 41-9. 46

Publication Year: 1985

Language: English

Title: **INFLUENCE OF DRAG REDUCING SURFACTANTS ON THE STRUCTURE OF TURBULENCE IN PIPE FLOWS.**

Author: **Bewersdorff, H. W. ; Ohlendorf, D.**

Abstract: The influence of two types of rod-like micelles on the **friction** behaviour in different pipe diameters was investigated by pressure drop measurements. In the turbulent flow regime each of the **surfactants** showed three characteristic flow regimes. The limits of these flow regimes could be influenced by changing the temperature and/or the **surfactant** concentration. The velocity profiles sometimes show a behaviour similar to that observed for dilute polymer...

...lie between VIRK's asymptotic curve and the laminar curve. An important advantage of using **surfactants** for studying the structure of turbulence at VIRK's maximum **drag** reduction asymptote is the absence of degradation. (Edited author abstract) 11 refs.

...Descriptors: Pipes; FLUID MECHANICS; **SURFACE ACTIVE AGENTS**...

Identifiers: **DRAG REDUCING SURFACTANTS ; PIPE FLOW TURBULENCE; VIRK'S DRAG REDUCTION ASYMPTOTE; TURBULENT FLOW**

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10/3,K/40 (Item 19 from file: 8)  
DIALOG(R)File 8: Ei Compendex(R)  
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01488658 E.I. Monthly No: EI8402012429 E.I. Yearly No: EI84048515  
Title: **VARIABLES AFFECTING DRAG REDUCTION BY NONIONIC SURFACTANT ADDITIVES.**

Author: **Zakin, Jacques L.** ; Lui, Hsiao-Lung  
Corporate Source: Ohio State Univ, Chemical Engineering Dep, Columbus, Ohio, USA  
Source: Chemical Engineering Communications v 23 n 1-3 Oct 1983 p 77-88  
Publication Year: 1983  
CODEN: CEGCAK ISSN: 0098-6445  
Language: ENGLISH

Title: **VARIABLES AFFECTING DRAG REDUCTION BY NONIONIC SURFACTANT ADDITIVES.**

Author: **Zakin, Jacques L.** ; Lui, Hsiao-Lung  
Abstract: For several polyoxyethylene alcohol nonionic **surfactants** not previously studied, the effects of **surfactant** structure, temperature, electrolytes, **surfactant** concentration, and mechanical degradation on **drag** reduction near their coacervation temperatures were investigated. Only linear alcohol derivatives were effective. Mechanically degraded solutions regain their **drag** reducing ability upon entering a low-shear region. 14 refs.

...Descriptors: **Drag** ; **SURFACE ACTIVE AGENTS**

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10/3,K/41 (Item 20 from file: 8)  
DIALOG(R)File 8:EI Compendex(R)  
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00680042 E.I. Monthly No: EI7708060787 E.I. Yearly No: EI77078388  
Title: **TRANSPORT OF CRUDE OIL AS OIL-IN-WATER EMULSIONS.**  
Author: **Zakin, J. L.** ; Pinaire, R.; Borgmeyer, M. E.  
Corporate Source: Univ of Mo, Rolla  
Source: American Society of Mechanical Engineers (Paper) n 77-FE-26 for Meet, Jun 15-17 1977 8 p  
Publication Year: 1977  
CODEN: ASMSA4 ISSN: 0402-1215  
Language: ENGLISH

Author: **Zakin, J. L.** ; Pinaire, R.; Borgmeyer, M. E.  
...Abstract: of oil viscosity, temperature and oil concentration on specific energy loss were evaluated. Measured turbulent **friction** factors consistently fell below those predicted by the Dodge and Metzner **friction** factor correlation, probably due to viscoelastic effects of the emulsion. Several polymer and **surfactant drag** reducers were tested in these emulsions, and high molecular weight polyacrylamides were found to be...  
...Descriptors: **Drag** ; **EMULSIONS**; **PETROLEUM**, **CRUDE**

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10/3,K/42 (Item 1 from file: 34)  
DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

07279619 Genuine Article#: 145TX No. References: 195  
Title: **Surfactant drag reduction**  
Author(s): **Zakin JL** ; **Bewersdorff HW**  
Corporate Source: OHIO STATE UNIV, DEPT CHEM ENGN/COLUMBUS//OH/43210; FH LAUSITZ, DEPT CHEM ENGN/D-01968 SENFTENBERG//GERMANY/  
Journal: **REVIEWS IN CHEMICAL ENGINEERING**, 1998 , V14, N4-5, P253-320  
ISSN: 0167-8299 Publication date: 19980000

Publisher: FREUND PUBLISHING HOUSE LTD, STE 500, CHESHAM HOUSE, 150 REGENT  
ST, LONDON W1R 5FA, ENGLAND  
Language: English Document Type: REVIEW

Title: Surfactant drag reduction  
Author(s): Zakin JL ; Bewersdorff HW  
, 1998

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10/3,K/43 (Item 2 from file: 34)  
DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

07022466 Genuine Article#: 107WX No. References: 0  
Title: Counterion induced microstructure transition in drag -reducing  
cationic surfactant CTAC solution, seen by cryo-TEM  
Author(s): Zheng Y; Lin Z; Zakin JL ; Talmon Y; Scriven LE; Davis HT  
Corporate Source: UNIV MINNESOTA,DEPT CHEM ENGN & MAT  
SCI/MINNEAPOLIS//MN/55455; UNIV MINNESOTA,CTR INTERFACIAL  
ENGN/MINNEAPOLIS//MN/55455; OHIO STATE UNIV,/COLUMBUS//OH/43210;  
TECHNION ISRAEL INST TECHNOL,/IL-32000 HAIFA//ISRAEL/  
Journal: ABSTRACTS OF PAPERS OF THE AMERICAN CHEMICAL SOCIETY, 1998 , V216  
, 1 (AUG 23), P323-COLL  
ISSN: 0065-7727 Publication date: 19980823  
Publisher: AMER CHEMICAL SOC, 1155 16TH ST, NW, WASHINGTON, DC 20036  
Language: English Document Type: MEETING ABSTRACT

Title: Counterion induced microstructure transition in drag -reducing  
cationic surfactant CTAC solution, seen by cryo-TEM  
Author(s): Zheng Y; Lin Z; Zakin JL ; Talmon Y; Scriven LE; Davis HT  
, 1998

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10/3,K/44 (Item 3 from file: 34)  
DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

05599286 Genuine Article#: WK060 No. References: 15  
Title: Effect of metal ions and compounds on the rheological properties of  
a drag -reducing cationic surfactant solution exhibiting  
shear-induced structure formation  
Author(s): Hu YT; Matthys EF (REPRINT)  
Corporate Source: UNIV CALIF SANTA BARBARA,MAT RES LAB/SANTA  
BARBARA//CA/93106 (REPRINT); UNIV CALIF SANTA BARBARA,MAT RES LAB/SANTA  
BARBARA//CA/93106; UNIV CALIF SANTA BARBARA,DEPT ENGN MECH/SANTA  
BARBARA//CA/93106  
Journal: JOURNAL OF COLLOID AND INTERFACE SCIENCE, 1997 , V186, N2 (FEB 15  
) , P352-359  
ISSN: 0021-9797 Publication date: 19970215  
Publisher: ACADEMIC PRESS INC JNL-COMP SUBSCRIPTIONS, 525 B ST, STE 1900,  
SAN DIEGO, CA 92101-4495  
Language: English Document Type: ARTICLE (ABSTRACT AVAILABLE)

Title: Effect of metal ions and compounds on the rheological properties of  
a drag -reducing cationic surfactant solution exhibiting  
shear-induced structure formation  
Author(s): Hu YT; Matthys EF (REPRINT)  
, 1997  
...Abstract: a 12.5/5 mM sodium salicylate (NaSal)/tris(2-hydroxyethyl)  
tallowalkyl ammonium acetate(TTAA) surfactant solution has been



studied phenomenologically. This solution normally exhibits shear-induced structure formation and strong **drag** reduction properties. The viscosity and N-1 buildup times under a constant shear rate increase...

...adding the chelating agent ethylenediaminetetraacetate to the contaminated solution. The rheological results are consistent with **drag** reduction experiments. The results show that chemical contamination may be an important issue for **drag** -reducing cationic **surfactant** additives used in industrial applications where such contaminants are present. (C) 1997 Academic Press.

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10/3,K/45 (Item 4 from file: 34)  
DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

04287108 Genuine Article#: QP232 No. References: 0  
**Title: MICELLAR STRUCTURE CHARACTERISTIC TIMES UNDER SHEAR-FLOW FOR A DRAG  
-REDUCING SURFACTANT SOLUTION - NORMAL STRESS STUDIES AND FLOW  
GEOMETRY-EFFECTS**  
Author(s): HU YT; **MATTHYS EF**  
Corporate Source: UNIV CALIF SANTA BARBARA, DEPT MECH ENGN/SANTA  
BARBARA//CA/93106  
Journal: ABSTRACTS OF PAPERS OF THE AMERICAN CHEMICAL SOCIETY, 1995 , V209  
, APR (APR 2), P134-COLL  
ISSN: 0065-7727  
Language: ENGLISH Document Type: MEETING ABSTRACT

**Title: MICELLAR STRUCTURE CHARACTERISTIC TIMES UNDER SHEAR-FLOW FOR A DRAG  
-REDUCING SURFACTANT SOLUTION - NORMAL STRESS STUDIES AND FLOW  
GEOMETRY-EFFECTS**  
Author(s): HU YT; **MATTHYS EF**  
, 1995

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10/3,K/46 (Item 5 from file: 34)  
DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

03733922 Genuine Article#: BB96C No. References: 19  
**Title: EFFECT OF COUNTERION STRUCTURE ON FLOW BIREFRINGENCE AND DRAG  
REDUCTION BEHAVIOR OF QUATERNARY AMMONIUM SALT CATIONIC SURFACTANTS**  
Author(s): SMITH BC; CHOU LC; LU B; **ZAKIN JL**  
Corporate Source: INT PAPER, ERLING RIIS RES LAB, POB 2787/MOBILE//AL/36652;  
BAKER PERFORMANCE CHEM/SAND SPRINGS//OK/74063; OHIO STATE UNIV, DEPT  
CHEM ENGN/COLUMBUS//OH/43210  
Journal: ACS SYMPOSIUM SERIES, 1994 , V578, P370-379  
ISSN: 0097-6156  
Language: ENGLISH Document Type: REVIEW (Abstract Available)

**Title: EFFECT OF COUNTERION STRUCTURE ON FLOW BIREFRINGENCE AND DRAG  
REDUCTION BEHAVIOR OF QUATERNARY AMMONIUM SALT CATIONIC SURFACTANTS**  
Author(s): SMITH BC; CHOU LC; LU B; **ZAKIN JL**  
, 1994

Abstract: Quaternary ammonium cationic **surfactants** with appropriate counterions are **friction** reducers and can reduce pumping energy requirements, increase water throughput or reduce pump size or pipeline diameter in closed loop district heating and cooling systems. **Drag** reduction occurs in the temperature range in which rod-like micelles

are present..

Variations in counterion chemical structures have major effects on the micelle structure and flow birefringence and **drag** reduction behavior of quaternary ammonium chloride **surfactants**. Isomers of ortho-, meta- and para-hydroxybenzoate, ortho-, meta- and para-chlorobenzoate and 1-hydroxy...

...hydroxy-1- and 3-hydroxy-2-naphthoate as counterions were investigated by flow birefringence and **drag** reduction measurements. Those systems showing birefringence also showed **drag** reduction behavior and their upper temperature limits of effectiveness coincided. The results also correlated with...

...their preferred environments can stabilize the sphere to rod transition and induce flow birefringence and **drag** reduction.

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10/3,K/47 (Item 6 from file: 34)  
DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

01855266 Genuine Article#: JG124 No. References: 13  
Title: THE INTERACTION OF POLYMER ADDITIVES WITH VORTICITY (A CASE-STUDY ON VORTEX RINGS)  
Author(s): GYR A; BEWERSDORFF HW ; BUHLER J; PAPANTONIOU D  
Corporate Source: SWISS FED INST TECHNOL, INST HYDROMECH & WATER RESOURCES MANAGEMENT/CH-8092 ZURICH//SWITZERLAND/; SWISS FED INST TECHNOL, INST HYDROMECH & WATER RESOURCES MANAGEMENT/CH-8092 ZURICH//SWITZERLAND/  
Journal: JOURNAL OF NON-NEWTONIAN FLUID MECHANICS, 1992 , V43, N2-3 (JUL), P179-194  
Language: ENGLISH Document Type: ARTICLE (Abstract Available)

Author(s): GYR A; BEWERSDORFF HW ; BUHLER J; PAPANTONIOU D  
, 1992  
...Abstract: of shear and elongation can enhance the reflection of vortices at the wall in turbulent, **drag** -reduced flows.  
...Identifiers--DILUTE POLYMER; **SURFACTANT** SOLUTIONS; EXTENSIONAL FLOW

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10/3,K/48 (Item 7 from file: 34)  
DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

00245046 Genuine Article#: DA938 No. References: 49  
Title: THE INFLUENCE OF PRE-SHEARING ON THE ELONGATIONAL BEHAVIOR OF DILUTE POLYMER AND SURFACTANT SOLUTIONS  
Author(s): VISSMANN K; BEWERSDORFF HW  
Corporate Source: SCHERING AG/BERGKAMEN//FED REP GER/; UNIV DORTMUND, DEPT CHEM ENGN/D-4600 DORTMUND 50//FED REP GER/  
Journal: JOURNAL OF NON-NEWTONIAN FLUID MECHANICS, 1990 , V34, N3, P 289-317  
Language: ENGLISH Document Type: ARTICLE

Title: THE INFLUENCE OF PRE-SHEARING ON THE ELONGATIONAL BEHAVIOR OF DILUTE POLYMER AND SURFACTANT SOLUTIONS  
Author(s): VISSMANN K; BEWERSDORFF HW  
, 1990  
Research Fronts: 88-2652 004 (DILUTE POLYMER-SOLUTIONS; ELONGATIONAL FLOW; APPARENT THICKENING BEHAVIOR; TURBULENT **DRAG** REDUCTION; NON-NEWTONIAN FLUID; TRANSIENT DEFORMATION)

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10/3,K/49 (Item 1 from file: 434)

DIALOG(R)File 434:SciSearch(R) Cited Ref Sci  
(c) 1998 Inst for Sci Info. All rts. reserv.

05516139 Genuine Article#: RW522 No. References: 11

**Title: VARIABLES AFFECTING DRAG REDUCTION BY NON-IONIC SURFACTANT ADDITIVES**

Author(s): ZAKIN JL ; LUI HL

Corporate Source: OHIO STATE UNIV, DEPT CHEM ENGN/COLUMBUS//OH/43210; UNIV MISSOURI/COLUMBIA//MO/65201; MALLINKRODT CHEM CO/ST LOUIS//MO/63166

Journal: CHEMICAL ENGINEERING COMMUNICATIONS, 1983 , V23, N1-3, P77-88

Language: ENGLISH Document Type: ARTICLE

**Title: VARIABLES AFFECTING DRAG REDUCTION BY NON-IONIC SURFACTANT ADDITIVES**

Author(s): ZAKIN JL ; LUI HL  
, 1983

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10/3,K/50 (Item 1 from file: 65)

DIALOG(R)File 65:Inside Conferences

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03627827 INSIDE CONFERENCE ITEM ID: CN038211500

**Enhancing Heat Transfer in Drag Reducing Surfactant Solutions**

Qi, Y.; Kawaguchi, Y.; Lin, Z.; Erwing, M.; Christensen, R. N.; Zakin, J. L.

CONFERENCE: European drag reduction working meeting-11th  
PROCEEDINGS OF THE EUROPEAN DRAG REDUCTION WORKING MEETING, 1999; 11TH  
P: 42

Institute of Hydrodynamics, ASCR, 1999

ISBN: 8023844423

LANGUAGE: English DOCUMENT TYPE: Conference Abstracts

CONFERENCE EDITOR(S): Chara, Z.; Pollert, J.

CONFERENCE SPONSOR: Academy of Sciences of the Czech Republic  
Czech Technical University in Prague

CONFERENCE LOCATION: Prague 1999; Sep (199909) (199909)

**Enhancing Heat Transfer in Drag Reducing Surfactant Solutions**

Qi, Y.; Kawaguchi, Y.; Lin, Z.; Erwing, M.; Christensen, R. N.; Zakin, J. L.

Institute of Hydrodynamics, ASCR, 1999

DESCRIPTORS: drag reduction; hydrodynamics; ASCR; LERMO

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10/3,K/51 (Item 2 from file: 65)

DIALOG(R)File 65:Inside Conferences

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03627810 INSIDE CONFERENCE ITEM ID: CN038211330

**Drag Reduction of Cationic Surfactant Solutions in Sand-Roughened Pipes**

Bewersdorff, H.-W. ; Bocker, A.

CONFERENCE: European drag reduction working meeting-11th  
PROCEEDINGS OF THE EUROPEAN DRAG REDUCTION WORKING MEETING, 1999; 11TH  
P: 12

Institute of Hydrodynamics, ASCR, 1999

ISBN: 8023844423

LANGUAGE: English DOCUMENT TYPE: Conference Abstracts  
CONFERENCE EDITOR(S): Chara, Z.; Pollert, J.  
CONFERENCE SPONSOR: Academy of Sciences of the Czech Republic  
Czech Technical University in Prague  
CONFERENCE LOCATION: Prague 1999; Sep (199909) (199909)

**Drag Reduction of Cationic Surfactant Solutions in Sand-Roughened Pipes**  
Bewersdorff, H.-W. ; Bocker, A.  
Institute of Hydrodynamics, ASCR, 1999  
DESCRIPTORS: drag reduction; hydrodynamics; ASCR; LERMO

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10/3,K/52 (Item 3 from file: 65)  
DIALOG(R)File 65:Inside Conferences  
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03627805 INSIDE CONFERENCE ITEM ID: CN038211286  
**Some Surprising Behaviors of Surfactant Drag Reducing Systems**  
Zakin, J. L. ; Myska, J.; Lin, Z.  
CONFERENCE: European drag reduction working meeting-11th  
PROCEEDINGS OF THE EUROPEAN DRAG REDUCTION WORKING MEETING, 1999; 11TH  
P: 5  
Institute of Hydrodynamics, ASCR, 1999  
ISBN: 8023844423  
LANGUAGE: English DOCUMENT TYPE: Conference Abstracts  
CONFERENCE EDITOR(S): Chara, Z.; Pollert, J.  
CONFERENCE SPONSOR: Academy of Sciences of the Czech Republic  
Czech Technical University in Prague  
CONFERENCE LOCATION: Prague 1999; Sep (199909) (199909)

**Some Surprising Behaviors of Surfactant Drag Reducing Systems**  
Zakin, J. L. ; Myska, J.; Lin, Z.  
Institute of Hydrodynamics, ASCR, 1999  
DESCRIPTORS: drag reduction; hydrodynamics; ASCR; LERMO

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10/3,K/53 (Item 4 from file: 65)  
DIALOG(R)File 65:Inside Conferences  
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03047805 INSIDE CONFERENCE ITEM ID: CN032307180  
**Influence of chemical structures of cationic surfactants on their drag reduction and rheological behaviors**  
Lu, B.; Li, X.; Talmon, Y.; Zakin, J. L.  
CONFERENCE: Rheology-International congress; 12th  
INTERNATIONAL CONGRESS ON RHEOLOGY, 1996; 12th P: 373-374  
Quebec, Canadian Rheology Group, Chemical Engineering Department, Laval University, 1996  
ISBN: 2980510904  
LANGUAGE: English DOCUMENT TYPE: Conference Papers  
CONFERENCE EDITOR(S): Ait-Kadi, A.  
CONFERENCE SPONSOR: Laval University Chemical Engineering Department  
Canadian Rheology Group  
CONFERENCE LOCATION: Quebec City, Canada  
CONFERENCE DATE: Aug 1996 (199608) (199608)

**Influence of chemical structures of cationic surfactants on their drag reduction and rheological behaviors**  
Lu, B.; Li, X.; Talmon, Y.; Zakin, J. L.  
Quebec, Canadian Rheology Group, Chemical Engineering Department, Laval

University, 1996

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10/3,K/54 (Item 5 from file: 65)  
DIALOG(R)File 65:Inside Conferences  
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03047734 INSIDE CONFERENCE ITEM ID: CN032306471  
**Effect of metal hydroxides on the viscoelasticity of a drag -reducing cationic surfactant solution**  
Hu, Y.; Matthys, E. F.  
CONFERENCE: Rheology-International congress; 12th  
INTERNATIONAL CONGRESS ON RHEOLOGY, 1996; 12th P: 234-236  
Quebec, Canadian Rheology Group, Chemical Engineering Department, Laval University, 1996  
ISBN: 2980510904  
LANGUAGE: English DOCUMENT TYPE: Conference Papers  
CONFERENCE EDITOR(S): Ait-Kadi, A.  
CONFERENCE SPONSOR: Laval University Chemical Engineering Department  
Canadian Rheology Group  
CONFERENCE LOCATION: Quebec City, Canada  
CONFERENCE DATE: Aug 1996 (199608) (199608)

**Effect of metal hydroxides on the viscoelasticity of a drag -reducing cationic surfactant solution**  
Hu, Y.; Matthys, E. F.  
Quebec, Canadian Rheology Group, Chemical Engineering Department, Laval University, 1996

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10/3,K/55 (Item 6 from file: 65)  
DIALOG(R)File 65:Inside Conferences  
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02745787 INSIDE CONFERENCE ITEM ID: CN028637523  
**Similarities and Differences in Drag Reduction Behavior of High Polymer and Surfactant Solutions**  
Zakin, J. ; Lin, Z.; Myska, J.  
CONFERENCE: Seawater drag reduction-International symposium  
P: 277-280  
np), 1998  
LANGUAGE: English DOCUMENT TYPE: Conference Papers  
CONFERENCE LOCATION: Newport, RI  
CONFERENCE DATE: Jul 1998 (199807) (199807)  
NOTE:  
Also known as ISSDR

**Similarities and Differences in Drag Reduction Behavior of High Polymer and Surfactant Solutions**  
Zakin, J. ; Lin, Z.; Myska, J.  
np), 1998  
DESCRIPTORS: seawater drag reduction; drag reduction; ISSDR

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10/3,K/56 (Item 7 from file: 65)  
DIALOG(R)File 65:Inside Conferences  
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02652241 INSIDE CONFERENCE ITEM ID: CN027618749  
**Micellar structure break-up and recovery in turbulent of drag -Reducing**

surfactant solutions

Gasljevic, K. ; Hoyer, K.; Matthys, E. F.  
CONFERENCE: European rheology conference-5th  
PROGRESS AND TRENDS IN RHEOLOGY, 1998; 5th P: 527-528  
Steinkopff, 1998  
ISBN: 3798511284  
LANGUAGE: English DOCUMENT TYPE: Conference Preprinted short papers  
CONFERENCE EDITOR(S): Emir, I.; Cvelbar, R.  
CONFERENCE LOCATION: Portoroz, Slovenia  
CONFERENCE DATE: Sep 1998 (199809) (199809)

Micellar structure break-up and recovery in turbulent of drag -Reducing  
surfactant solutions

Gasljevic, K. ; Hoyer, K.; Matthys, E. F.  
Steinkopff, 1998

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10/3,K/57 (Item 8 from file: 65)

DIALOG(R)File 65:Inside Conferences

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01369646 INSIDE CONFERENCE ITEM ID: CN013586500

Flows of surfactant drag reducers for decreasing pumping energy demand  
in district heating systems

Pollert, J.; Svejksky, K.; Komrzy, P.; Zakin, J. L.  
CONFERENCE: Proceedings of the International Association for Hydraulic  
Research Vol 2; Industrial hydraulics and multi-phase flows-Congress;  
26th.

PROCEEDINGS OF THE CONGRESS- INTERNATIONAL ASSOCIATION FOR HYDRAULIC  
RESEARCH, 1995; CONF 26; VOL 2 P: 152-157

Thomas Telford, 1995

LANGUAGE: English DOCUMENT TYPE: Conference Papers

CONFERENCE EDITOR(S): Ervine, D. A.; Leschziner, M. A.; Grass, A. J.;  
Gardiner, J.

CONFERENCE SPONSOR: International Association for Hydraulic Research

CONFERENCE LOCATION: London

CONFERENCE DATE: Sep 1995 (19950) (19950)

NOTE:

Hydraulics research and its application next century

Flows of surfactant drag reducers for decreasing pumping energy demand  
in district heating systems

Pollert, J.; Svejksky, K.; Komrzy, P.; Zakin, J. L.  
Thomas Telford, 1995

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10/3,K/58 (Item 9 from file: 65)

DIALOG(R)File 65:Inside Conferences

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00570467 INSIDE CONFERENCE ITEM ID: CN005533247

Use of Mixed Cations and Mixed Counter-Ions to Extend the Effective  
Temperature Range for Drag Reducing Surfactant Additives

Chou, L.-C.; Zakin, J. L.

CONFERENCE: Fluids for district heating-International symposium  
P: 75-86

Technical University of Denmark, 1991

ISBN: 8788038238

LANGUAGE: English DOCUMENT TYPE: Conference Papers

CONFERENCE EDITOR(S): Bohm, B.

CONFERENCE SPONSOR: Nordic Council of Ministers Energy Research  
Cooperation  
Technical University of Denmark Laboratory of Heating and Air  
Conditioning  
CONFERENCE LOCATION: Copenhagen  
CONFERENCE DATE: Apr 1991 (199104) (199104)

**Use of Mixed Cations and Mixed Counter-Ions to Extend the Effective  
Temperature Range for Drag Reducing Surfactant Additives**

Chou, L.-C.; Zakin, J. L.

Technical University of Denmark, 1991

Set	Items	Description
S1	0	AU=(MATTHYS E? OR MATTHYS, E? OR GASLIEVIC K? OR GASLJEVIC K? OR GASLJIEVIC K? OR GASLIEVIC, K? OR GASLJEVIC, K? OR GASLJIEVIC, K?)
S2	3	ERIC(2W)MATTHYS OR (KAZIMIR OR CASIMIR) (2W) (GASLIEVIC OR GASLJEVIC OR GASLJIEVIC)
S3	0	AU=(BEWERSDORFF H? OR BEWERSDORFF, H?)
S4	0	H?(2W)BEWERSDORFF
S5	0	AU=(ZAKIN J? OR ZAKIN, J?)
S6	2	JACQUES(2W)ZAKIN
S7	1297	(DRAG? OR FRICTION? OR (HEAT? OR THERM?) (2N)EXCHANG?) AND - (SURFACTANT? OR SURFACE()ACTIVE)
S8	5	S1:S6
S9	0	S8 AND S7
S10	5	S8:S9
S11	5	RD (unique items)

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File 613:PR Newswire 1999-2004/May 18  
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File 809:Bridge World Markets News 1989-1999/Dec 31  
(c) 1999 Bridge

File 810:Business Wire 1986-1999/Feb 28  
(c) 1999 Business Wire

File 813:PR Newswire 1987-1999/Apr 30  
(c) 1999 PR Newswire Association Inc

File 20:Dialog Global Reporter 1997-2004/May 18  
(c) 2004 The Dialog Corp.

File 570:Gale Group MARS(R) 1984-2004/May 18  
(c) 2004 The Gale Group



11/3,K/3 (Item 2 from file: 635)  
DIALOG(R)File 635:Business Dateline(R)  
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0083416 89-07076

**Veterinarian, OSU Reap Big Bucks From Discovery of Vaccine for Cats**

Kimmins, Dick

Business First-Columbus (Columbus, OH, US), V5 N20 s1 p1

PUBL DATE: 890206

WORD COUNT: 1,257

DATLINE: Mansfield, OH, US

TEXT:

...the research is not a factor in seeking research grants.

Two months ago, for example, **Jacques L. Zakin**, chairman of OSU's  
Department of Chemical Engineering, and two colleagues received a \$57,726  
...

(FILE 'HOME' ENTERED AT 14:22:16 ON 18 MAY 2004)

FILE 'ALUMINIUM, HCAPLUS, ENERGY, MATBUS, METADEX' ENTERED AT 14:22:45 ON  
18 MAY 2004

L1 327019 S (HEAT? OR THERM?) (W) (EXCHANG? OR TRANSFER?)  
L2 238612 S SURFACTANT? OR SURFACE (W) ACTIVE OR SURFACEACTIVE (W) AGENT?  
L3 1592 S L1 AND L2  
L4 3556085 S MOLECUL? OR MICEL? OR MICROSTRUCTUR? OR MICRO (W) STRUCTUR?  
L5 187 S L3 AND L4  
L6 193131 S DRAG? OR FRICTION?  
L7 39 S L5 AND L6  
L8 39 DUP REM L7 (0 DUPLICATES REMOVED)

L8 ANSWER 1 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB Solns. containing **drag** reducing additives also show reduced **heat transfer** which limits their use in district heating and cooling recirculation systems where **heat exchange** is critical. In this study, static mixers A and B and honeycombs were installed at the entrance to a **heat exchanger** to break the solution **microstructure** temporarily and thereby enhancing their **heat transfer** ability when passing through the **heat exchanger**. The effectiveness of the destructive devices in enhancing the **heat transfer** ability of **drag** reducing cationic and mixed zwitterionic/anionic **surfactant** solns. was investigated together with the **microstructure** recovery time and pressure drop penalty paid for the **heat transfer** enhancement.

ACCESSION NUMBER: 2003:725334 HCAPLUS  
DOCUMENT NUMBER: 139:383263  
TITLE: Enhancing **heat transfer** ability of **drag** reducing **surfactant** solutions with static mixers and honeycombs  
AUTHOR(S): Qi, Yunying; Kawaguchi, Yasuo; Christensen, Richard N.; Zakin, Jacques L.  
CORPORATE SOURCE: Department of Chemical Engineering, The Ohio State University, Columbus, OH, 43210, USA  
SOURCE: International Journal of Heat and Mass Transfer (2003), 46(26), 5161-5173  
CODEN: IJHMAK; ISSN: 0017-9310  
PUBLISHER: Elsevier Science B.V.  
DOCUMENT TYPE: Journal  
LANGUAGE: English  
REFERENCE COUNT: 13 THERE ARE 13 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

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L8 ANSWER 2 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB The thermal pattern on a heated wall was studied for the flow of water and **drag**-reducing **surfactant** solns. in a channel. The wall of the channel was made of a thin foil, which was heated by d.c. The temperature of the foil, which reflects the local flow velocities, was measured by an IR technique with high spatial and temperature resolution. The **microstructure** of the **surfactant** solution was studied by direct imaging cryogenic temperature transmission electron microscopy (Cryo-TEM). The most prevalent structures observed are thread-like **micelles**, which were suggested to cause the modification of the thermal patterns.

ACCESSION NUMBER: 2003:761107 HCAPLUS  
DOCUMENT NUMBER: 139:397387  
TITLE: The Effect of a Cationic **Surfactant** on Turbulent Flow Patterns  
AUTHOR(S): Hetsroni, G.; Mosyak, A.; Talmon, Y.; Bernheim-Groswasser, A.; Zakin, J. L.  
CORPORATE SOURCE: Department of Mechanical Engineering, Technion-Israel Institute of Technology, Haifa, 32000, Israel  
SOURCE: Journal of Heat Transfer (2003), 125(5), 947-950  
CODEN: JHTRAO; ISSN: 0022-1481  
PUBLISHER: American Society of Mechanical Engineers  
DOCUMENT TYPE: Journal  
LANGUAGE: English  
REFERENCE COUNT: 14 THERE ARE 14 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

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L8 ANSWER 3 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB While major redns. in pumping energy requirements can be achieved by adding **drag** reducing **surfactant** solns. in recirculating district heating and cooling (DHC) systems, special

techniques are needed to enhance the reduced **heat-transfer** coeffs. In this paper, the use of ultrasonic energy to enhance the **heat-transfer** ability of **drag** reducing **surfactant** solns. is described. The **surfactant** solns. tested include two viscoelastic **drag** reducing **surfactant** solns.: Ethoquad T13-50/NaSal (5 mM/8.75 mM) (S1) and SPE98330/HCHO/Trilon A (1500 ppm/150 ppm/500 ppm) (S2) and a **drag** reducing **surfactant** solution Arquad S-50/NaSal (5 mM/12.5 mM) (S3) whose viscoelasticity cannot be detected by our rheometer. Significant **heat-transfer** enhancements were observed for the two viscoelastic **drag** reducing **surfactant** solns., S1 and S2, with ultrasonic energy while surprisingly, only small effects on enhancing the **heat-transfer** ability of S3 were observed. The effectiveness of ultrasonic energy in enhancing the **heat-transfer** ability of viscoelastic **drag** reducing **surfactant** solns. depends on the solution temperature, ultrasonic intensity and also the **microstructure** of the **surfactant** solns. The relationships among solution viscoelasticity, vortex inhibition and **heat-transfer** reduction of the **surfactant** solns. are also discussed.

ACCESSION NUMBER: 2003:925213 HCAPLUS  
DOCUMENT NUMBER: 140:96092  
TITLE: Enhancing **heat-transfer** ability of **drag** reducing **surfactant** solutions with ultrasonic energy  
AUTHOR(S): Qi, Yunying; Weavers, Linda K.; Zakin, Jacques L.  
CORPORATE SOURCE: Department of Chemical Engineering, The Ohio State University, Columbus, OH, 43210, USA  
SOURCE: Journal of Non-Newtonian Fluid Mechanics (2003), 116(1), 71-93  
CODEN: JNFMDI; ISSN: 0377-0257  
PUBLISHER: Elsevier Science B.V.  
DOCUMENT TYPE: Journal  
LANGUAGE: English  
REFERENCE COUNT: 36 THERE ARE 36 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

L8 ANSWER 4 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB The effect of non-ionic **surfactant** addition to brine ((CH<sub>2</sub>OH)<sub>2</sub> solution) on **drag** and **heat transfer** reduction in a straight pipe flow is studied in terms of **surfactant** concentration, solution temperature, and brine concentration C16H35N(C<sub>2</sub>H<sub>4</sub>OH)<sub>2</sub>O (ODEAO), was used as a flow **drag** reducing additive and added to brine solution as a solvent at concentration of 30 or 40%. The **friction** factor  $\lambda$ , the modified Prandtl number  $Pr'$ , and the relation  $Nu/Pr'^{1/3}$  are evaporating as function of the modified Reynolds number  $Re'$ . In the laminar flow region Newtonian behavior was observed, whereas in the turbulent flow region the values are lower than those for an Newtonian fluid due to the ODEAO rod-like **micelles** interaction.

ACCESSION NUMBER: 2003:839053 HCAPLUS  
DOCUMENT NUMBER: 140:148281  
TITLE: Flow and **heat transfer** characteristics of brine with flow **drag** reduction additive  
AUTHOR(S): Haruki, Naoto; Inaba, Hideo; Horibe, Akihiko; Nakata, Toru; Sato, Kenji  
CORPORATE SOURCE: Department of Mechanical Engineering, Okayama University, Okayama, 700-8530, Japan  
SOURCE: Thermal Science and Engineering (2003), 11(4), 43-44  
CODEN: TSENFR; ISSN: 0918-9963  
PUBLISHER: Nippon Dennetsu Gakkai  
DOCUMENT TYPE: Journal  
LANGUAGE: English

REFERENCE COUNT: 5 THERE ARE 5 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

L8 ANSWER 5 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB Unavailable

ACCESSION NUMBER: 2004:89899 HCAPLUS

TITLE: Investigation of relationships among  
**microstructure**, rheology, **drag**  
reduction and **heat transfer** of  
**drag** reducing **surfactant** solutions

AUTHOR(S): Qi, Yunying

CORPORATE SOURCE: Ohio State Univ., Columbus, OH, USA

SOURCE: (2002) 523 pp. Avail.: UMI, Order No. DA3083783  
From: Diss. Abstr. Int., B 2003, 64(3), 1372

DOCUMENT TYPE: Dissertation

LANGUAGE: English

L8 ANSWER 6 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB This paper reports how **heat transfer** can be augmented by inserting a **micelle** squeezer at the inlet of the turbulent pipe flow **drag**-reduced by **surfactant** additives. The **micelle** squeezer gives very high shear to the flow and the rod-like **micelles** formed with **surfactant** mols., which remarkably reduce both **drag** force of the flow and **heat transfer**, are broken by the high flow shear at the flow inlet. From this, the **drag** force is recovered in the very limited region below the **micelle** squeezer, but also **heat transfer** is recovered in the enough regions required for exchanging heat. This strategy can be applied for **heat exchangers**, which occupy the small part of district cooling flow system.

ACCESSION NUMBER: 2002:337672 HCAPLUS

DOCUMENT NUMBER: 137:34963

TITLE: **Heat transfer** augmentation in a  
**surfactant** solution flow with an insertion of  
a **micelle** squeezer

AUTHOR(S): Kishimoto, Akira; Okunishi, Takahiro; Suzuki, Hiroshi;  
Usui, Hiromoto

CORPORATE SOURCE: Research & Development Department, Osaka Gas Co.,  
LTD., 6-19 9 Torishima, Konohana-ku, Osaka, 554-0051,  
Japan

SOURCE: Nippon Kikai Gakkai Ronbunshu, B-hen (2002), 68(666),  
469-472

CODEN: NKGBDD; ISSN: 0387-5016

PUBLISHER: Nippon Kikai Gakkai

DOCUMENT TYPE: Journal

LANGUAGE: Japanese

L8 ANSWER 7 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB The **heat transfer** enhancement of **drag**

-reducing flow of high Reynolds number in a two-dimensional channel by utilizing the characteristic of fluid was studied. As the networks of rod-like **micelles** in **surfactant** solution are responsible for suppressing the turbulence in **drag**-reducing flow, destruction of the structure of networks was considered to eliminate the **drag** reduction and prevent **heat transfer** deterioration. By inserting wire mesh in the channel against the flow, the **drag**-reducing function of the **micellar** structure in **surfactant** aqueous solution was successfully switched off. With the Reynolds number close to the first critical Reynolds number, the **heat transfer** coefficient in the region downstream of the mesh can be improved significantly, reaching the same level as that of water. The region with turbulent **heat transfer** downstream of the mesh becomes smaller as the concentration of **surfactant** in the solution

increases. Three types of mesh of different wire diameter and opening space were evaluated for their effect in promoting **heat transfer** and the corresponding pressure loss due to blockage of the mesh. The turbulent intensities were measured downstream from the mesh by using a Laser Doppler Velocimetry (LDV) system. The results indicated that the success of **heat transfer** enhancement is due to the strong turbulence promoted by the mesh which destroys the network of rod-like **micelles** by applying high shear stress and thus relaxing the shear induced state (SIS).

ACCESSION NUMBER: 2001:647666 HCAPLUS  
DOCUMENT NUMBER: 135:305649  
TITLE: **Heat transfer** enhancement to the **drag**-reducing flow of **surfactant** solution in two-dimensional channel with mesh-screen inserts at the inlet  
AUTHOR(S): Li, Peiwen; Kawaguchi, Yasuo; Daisaka, Hisashi; Yabe, Akira; Hishida, Koichi; Maeda, Masanobu  
CORPORATE SOURCE: The Energy Conservation Center, Mechanical Engineering Laboratory AIST, MITI, Japan, Japan  
SOURCE: Journal of Heat Transfer (2001), 123(4), 779-789  
CODEN: JHTRAO; ISSN: 0022-1481  
PUBLISHER: American Society of Mechanical Engineers  
DOCUMENT TYPE: Journal  
LANGUAGE: English  
REFERENCE COUNT: 35 THERE ARE 35 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

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L8 ANSWER 8 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB Cationic **surfactant** solns. that form rod-like **micelles** are known to cause remarkable **drag**-reducing effect. However, **heat transfer** reduction also occurs simultaneously in the **drag**-reducing systems. Application of this **drag**-reduction technol. to the **heat transfer** medium in a district heating and cooling system may thus decrease the **heat transfer** capacity of the **heat exchanger** in the refrigerator. In this work, we evaluated the **heat transfer** characteristics of a **drag** reducing aqueous solution containing oleylbis(hydroxyethyl)methylammonium chloride as the cationic **surfactant** and sodium salicylate as the counter ion. The **heat transfer** tubes examined were smooth copper tubes and the internally grooved tube with spiral ridges inside, both of which are employed in refrigerators In the grooved tube with ridge of narrow pitch, **heat transfer** reduction did not occur in the velocity range. It was also found that the **heat transfer** reduction correlated well with the wall shear rate.

ACCESSION NUMBER: 2001:417402 HCAPLUS  
DOCUMENT NUMBER: 134:368834  
TITLE: Influences of the inner-surface conditions of circular tubes on the **heat transfer** in a **surfactant drag**-reduction system  
AUTHOR(S): Kishimoto, Akira; Suzuki, Hiroshi; Usui, Hiromoto  
CORPORATE SOURCE: Research and Development Department, Osaka Gas Co., Ltd., Osaka, 554-0051, Japan  
SOURCE: Kagaku Kogaku Ronbunshu (2001), 27(3), 347-351  
CODEN: KKRBAW; ISSN: 0386-216X  
PUBLISHER: Kagaku Kogakkai  
DOCUMENT TYPE: Journal  
LANGUAGE: Japanese

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L8 ANSWER 9 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB The **heat transfer** and pressure drop measurements of an aqueous cationic **surface active** agent (Ethoquad T/13-50 2300 wppm with NaSal 2000 wppm) solution are carried out in a 2:1 rectangular channel under turbulent flow condition. These measurements are compared

with results for a Newtonian fluid (water) and a viscoelastic polymer solution (Separan AP-273 500 wppm). The test fluid developed hydrodynamically from the beginning of the rectangular duct up to 205 hydraulic diameter where the heating of the test fluid started and continued until 533 hydraulic diameter. The thermal boundary condition corresponding to axially constant heat flux was adopted for three heating configurations: (1) top longer wall heated, other walls adiabatic; (2) bottom longer wall heated, other walls adiabatic; and (3) top and bottom walls heated, side narrow walls adiabatic. The measured fully developed **friction** factors for the flow of **surfactant** solution were much lower than the values for water and were somewhat lower but of the same order of magnitude as found for the **drag** reducing aqueous high **mol.** weight polymer solns. The measured **heat transfer** factor for the **surfactant** solution showed a substantial reduction compared to the Dittus-Boelter prediction for Newtonian fluids and measured **heat transfer** factor for water. For the Kozichi generalized Reynolds nos. (Re) ranging from 15,000-33,000, the **heat transfer** reduction is **apprx.** 87%. The **heat transfer** reduction rate is somewhat larger but are comparable to the results measured for the polymer solution

ACCESSION NUMBER: 2001:464138 HCAPLUS  
DOCUMENT NUMBER: 135:78794  
TITLE: Experimental study of the rheological and **heat transfer** behavior of an aqueous **surfactant** solution (3rd report - turbulent **heat transfer** study)  
AUTHOR(S): Ishiguro, Suguru  
CORPORATE SOURCE: Dep. Mechanical Eng., Univ. Illinois, Chicago, IL, 60607-7074, USA  
SOURCE: Thermal Science and Engineering (2001), 9(2), 21-30  
CODEN: TSENFR; ISSN: 0918-9963  
PUBLISHER: Nippon Dennetsu Gakkai  
DOCUMENT TYPE: Journal  
LANGUAGE: English  
REFERENCE COUNT: 23 THERE ARE 23 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

L8 ANSWER 10 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN  
AN 2001(6):27628 ENERGY

AB The present review article presents the current status of some researches on thermal energy transportation using functionally thermal fluid, which is a mixture of heat transfer medium like water and other material with or without phase change like a paraffin wax as a latent heat storage material. This functionally thermal fluid offers attractive opportunities for thermal energy transportation and heat transfer enhancement of heat exchanger. This article describes classification and characteristics of functionally thermal fluids and their application. Referring to functionally thermal fluid for the usage of sensible heat, some viscoelastic fluids for flow drag reduction in a thermal energy transport system such as aqueous polymer solution and surfactant solution are mentioned. On the other hand, this article describes heat transfer and hydrodynamic characteristics of some phase change slurries like ice slurry, phase change microemulsion slurry, phase change micro-encapsulated slurry, clathrate slurry and shape-stabilized paraffin and polyethylene pellets as functionally thermal fluids using latent heat between solid and liquid phases. Finally, it leads to the conclusion that some functionally thermal fluids are very useful for the advanced thermal energy transportation and heat exchanger systems. (authors)

TITLE: New challenge in advanced thermal energy transportation using functionally thermal fluids.  
AUTHOR: Inaba, H. (Okayama Univ., Div. of Energy Conversion Science, Graduate School of Natural Science and Technology (Japan))  
SOURCE: International Journal of Thermal Sciences (Oct-Dec

2000) v. 39(9-11) p. 991-1003. 11 refs.  
ISSN: 1290-0729

DOCUMENT TYPE: Journal  
COUNTRY: France  
LANGUAGE: English  
FIELD AVAILABILITY: AB

L8 ANSWER 11 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB This paper has focused to investigate the flow **drag** reduction and **heat transfer** characteristics of **surfactant** solution in curved pipes. In this study, Dodecyltrimethyl Ammonium Chloride ( $\text{C}_{12}\text{H}_{25}\text{N}(\text{CH}_3)_3 = 263.89$ ) was used as a **surfactant**, and Sodium Salicylate ( $\text{C}_7\text{H}_5\text{NaO}_3 = 160.10$ ) was added to the **surfactant** solution for the enhancement of making rod-like **micelle** **surfactant** structure. From the exptl. results of flow **drag** resistance of the **surfactant** solution and water in curved tubes, it was found that the **friction** factor of the **surfactant** solution flow decreased markedly in comparison with that of water flow in a turbulent flow. Therefore, the flow **drag** reduction effect was examined in detail in some curved pipes. It was seen that 4 local flow resistances of the position of upside, downside, inside and outside of the curved tube were different one another. The angle and radius of curved test tubes exerted the influence on the **friction** factor of the **surfactant** solution flow. The **heat transfer** of the **surfactant** solution and water flows was measured in the same curved tubes under the constant heat flux heating condition. The **heat transfer** in the laminar flow measured in curved tubes increased as compared with that in a straight tube. This increase of the **heat transfer** was caused by the secondary flow in the curved tubes. However in the turbulent flow of the **surfactant** solution, it was seen that the **heat transfer** reduction effect was confirmed in the same measuring range as the flow **drag** reduction one. As a result, the secondary flow in the curved tube provided the decreasing tendency of both the flow **drag** and **heat transfer** reduction effect.

ACCESSION NUMBER: 2002:665214 HCAPLUS

DOCUMENT NUMBER: 137:234571

TITLE: Flow and **heat transfer** characteristics of water solution with flow **drag** reduction additive in curved tubes

AUTHOR(S): Inaba, Hideo; Haruki, Naoto; Horibe, Akihiko

CORPORATE SOURCE: The Graduate School of Natural Science and Technology, Okayama University, Japan

SOURCE: Proceedings of Symposium on Energy Engineering in the 21st Century, Hong-Kong, China, Jan. 9-13, 2000 (2000), Volume 2, 723-730. Editor(s): Cheng, Ping. Begell House, Inc.: New York, N. Y.  
CODEN: 69DAS2

DOCUMENT TYPE: Conference

LANGUAGE: English

REFERENCE COUNT: 5 THERE ARE 5 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

L8 ANSWER 12 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB In order to optimize the mol. structure of cationic **surfactants** having some hydroxyethyl (HE) groups to prevent the **heat transfer** reduction in a **drag** reducing system, an exptl. study has been performed. **Drag** reduction rates and relaxation times were measured for four types of **surfactants** having different number of HE groups from zero to three. Special attention was paid to the effect of the concentration of **surfactants**. From the results, when the relaxation time of the **micelle** reformation becomes larger, the region of **drag** reduction disappearance where **heat transfer** recovers up to one for water becomes wider



below the pump, which destroys **micelle** structure. The relaxation time depends seriously on the number of HE groups of **surfactant mol.** and on the concentration of **surfactants**. Then, it is concluded that **drag** reduction and **heat transfer** recovery can be controlled by changing the number of HE groups and the concentration of **surfactants** in accordance with the situation of district heating and cooling system.

ACCESSION NUMBER: 2001:119385 HCAPLUS  
DOCUMENT NUMBER: 135:154403  
TITLE: Optimization of **molecular** structure of cationic **surfactants** to prevent the **heat transfer** reduction in a **drag**-reducing system  
AUTHOR(S): Usui, Hiromoto; Suzuki, Hiroshi; Okunishi, Takahiro; Sugawara, Hitoshi; Yamauchi, Makoto  
CORPORATE SOURCE: Department of Chemical Science and Engineering, Kobe University, Kobe, 657-8501, Japan  
SOURCE: Proceedings of the International Congress on Rheology, 13th, Cambridge, United Kingdom, Aug. 20-25, 2000 (2000), Volume 2, 294-296. Editor(s): Binding, David M. British Society of Rheology: Glasgow, UK.  
CODEN: 69AYDA  
DOCUMENT TYPE: Conference  
LANGUAGE: English  
REFERENCE COUNT: 9 THERE ARE 9 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

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L8 ANSWER 13 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB The title method comprises adding amine oxides containing specific C nos. of alkyl, alkylene, diolefin, polyolefin, acetylene hydrocarbon series, and/or alkylether amine oxides containing ethylene oxide, propylene oxide, butylene oxide or their mixts., especially at 0.05-1.0 weight% concentration for forming **micelles** in aqueous solns. as high-d. **heat transfer** **surfactants**.

ACCESSION NUMBER: 1999:317075 HCAPLUS  
DOCUMENT NUMBER: 131:7445  
TITLE: Method for reducing of **friction drag** in pipeline transport of aqueous **heat-transfer** medium  
INVENTOR(S): Nakata, Itaru; Nagai, Jotaro; Nobuchika, Kazuo  
PATENT ASSIGNEE(S): Toho Chemical Industry Co., Ltd., Japan  
SOURCE: Jpn. Kokai Tokkyo Koho, 7 pp.  
CODEN: JKXXAF  
DOCUMENT TYPE: Patent  
LANGUAGE: Japanese  
FAMILY ACC. NUM. COUNT: 1  
PATENT INFORMATION:

PATENT NO.	KIND	DATE	APPLICATION NO.	DATE
JP 11131088	A2	19990518	JP 1997-314558	19971031
PRIORITY APPLN. INFO.:			JP 1997-314558	19971031
OTHER SOURCE(S):	MARPAT	131:7445		

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L8 ANSWER 14 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN  
AN 2000(6):22699 ENERGY  
AB The turbulent characteristics of a surfactant water solution in changing from drag-reducing flow to turbulent flow inside a two-dimensional smooth channel and in changing from turbulent flow to drag-reducing flow in the same channel with a mesh plug were investigated through LDV measurement in this study. The mesh plug was used to exert high shear stress to destroy micelle structures in the surfactant solution so that turbulence could be produced for better heat transfer. The two-component LDV system

was installed on a movable platform, which could be moved streamwise of the flow to measure the two-dimensional velocity at different stations downstream from the mesh plug. The surfactant tested was Cetyltrimethyl ammonium chloride (C16H33N(CH3)3Cl, abbreviated as CTAC). Local tap water was used as solvent and same weight concentration of sodium salicylate was used as the counter-ion material. The investigation of turbulent parameters for the drag-reducing flow with increasing Reynolds number showed that when the Reynolds number exceeded the drag-reducing region, the turbulent character was the same as that of water. The turbulent parameters of surfactant flow downstream the mesh plug showed that the high heat transfer region had the same turbulent intensity as that of water flow. As the critical Reynolds number was approached, it became easier to obtain such a turbulent region by mesh plug. In such cases, the mesh helped to create high wall shear stress and therefore to destroy the super-ordered structures of rod-like micelles for introducing turbulence. However, it was found that the turbulent intensities of the velocity gradually decreased to the same as those of drag-reducing flow downstream from the mesh because the mesh plug only produced a local high shear stress

TITLE: Turbulence structure of drag-reducing surfactant solution in two-dimensional channel with additional heat transfer enhancement method.

AUTHOR: Li, P.W.; Daisaka, H.; Kawaguchi, Y.; Yabe, A.; Hishida, K.; Maeda, M.

SOURCE: Proceedings of the 5th ASME/JSME thermal engineering joint conference. AIST, MITI, Tsukuba (Japan) New York, NY: American Society of Mechanical Engineers. 1999. p. 8, Paper AJTE99.6446 of [3600 p.]. 1 CD-ROM. Operating system required: Windows i386(tm), i486(tm), Pentium (R) or Pentium Pro, MS Windows 3.1, 95, or NT 3.51, 8 MB RAM, MacIntosh and Power MacIntosh with a 68020 or greater processor, System software version 7.1, 3.5 MB RAM (5 MB for PowerMac) 6 MB available hard-disk space, Unix. American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016 (US); \$500.00. Conference: 5th ASME/JSME Thermal Engineering Joint Conference, San Diego, CA (United States), 14 Mar 1999 - 19 Mar 1999

DOCUMENT TYPE: Book Article; Conference

COUNTRY: United States

LANGUAGE: English

FIELD AVAILABILITY: AB

L8 ANSWER 15 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB The turbulent characteristics of a **surfactant** water solution in changing from **drag**-reducing flow to turbulent flow inside a two-dimensional smooth channel and in changing from turbulent flow to **drag**-reducing flow in the same channel with a mesh plug were investigated through LDV measurement in this study. The mesh plug was used to exert high shear stress to destroy **micelle** structures in the **surfactant** solution so that turbulence could be produced for better **heat transfer**. The two-component LDV system was installed on a movable platform, which could be moved streamwise of the flow to measure the two-dimensional velocity at different stations downstream from the mesh plug. The **surfactant** tested was cetyltrimethyl ammonium chloride. Local tap water was used as solvent and the same weight concentration of sodium salicylate was used as the counter-ion material. The investigation of turbulent parameters for the **drag**-reducing flow with increasing Reynolds number showed that when the Reynolds number exceeded the **drag**-reducing region, the turbulent character was the same as that of water. The turbulent parameters of **surfactant** flow downstream the mesh plug showed that the high

heat transfer region had the same turbulent intensity as that of water flow. As the "critical Reynolds number" was approached, it became

easier to obtain such a turbulent region by mesh plug. In such cases, the mesh helped to create high wall shear stress and therefore to destroy the super-ordered structures of rod-like micelles for introducing turbulence. However, it was found that the turbulent intensities of the velocity gradually decreased to the same as those of drag reducing flow downstream from the mesh because the mesh plug only produced a local high shear stress.

ACCESSION NUMBER: 2000:660748 HCAPLUS  
DOCUMENT NUMBER: 133:209936  
TITLE: Turbulence structure of drag-reducing surfactant solution in two-dimensional channel with additional heat transfer enhancement method  
AUTHOR(S): Li, P. W.; Daisaka, H.; Kawaguchi, Y.; Yabe, A.; Hishida, K.; Maeda, M.  
CORPORATE SOURCE: Mechanical Engineering Laboratory, AIST, MITI, Tsukuba, 305-8564, Japan  
SOURCE: Proceedings of the ASME/JSME Thermal Engineering Joint Conference, 5th, San Diego, CA, United States, Mar. 14-19, 1999 (1999), 1893-1900. American Society of Mechanical Engineers: New York, N. Y.  
CODEN: 69AEKP  
DOCUMENT TYPE: Conference; (computer optical disk)  
LANGUAGE: English  
REFERENCE COUNT: 15 THERE ARE 15 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

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L8 ANSWER 16 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB A review, with 32 refs., of the title subject, including rheol. properties of surfactant-containing systems, characteristics of turbulence and turbulent flow, and drag reduction applications for energy conservation in relation to heating and air conditioning, as well as enhancing heat exchanger performance.

ACCESSION NUMBER: 1999:621506 HCAPLUS  
DOCUMENT NUMBER: 131:352994  
TITLE: Drag reduction by surfactant additives and its applications  
AUTHOR(S): Kawaguchi, Yasuo  
CORPORATE SOURCE: Department of Energy Engineering, Mechanical Engineering Laboratory, Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI), Japan  
SOURCE: Hyomen (1999), 37(8), 443-450  
CODEN: HYMN7; ISSN: 0367-648X  
PUBLISHER: Koshinsha  
DOCUMENT TYPE: Journal; General Review  
LANGUAGE: Japanese

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L8 ANSWER 17 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB A series of exptl. studies with an aqueous drag reducing surfactant solution was carried out in the aim of understanding the fluid mechanics and heat transfer characteristics of the solution. As the beginning of this fluid dynamics and heat transfer studies relating to the drag reducing surfactant solution, this report mainly deals with rheol. properties of the surfactant solution. Viscosity measurements of the surfactant solution (Ethoquad T/13-50) showed that the apparent viscosity of the solution increased with time when sheared at a fixed shear rate. This behavior is generally believed to be the results of microstructure change of the micelles (shear-induced-structure or SIS). Upon cessation of the shearing, the

apparent viscosity of the solution decreases to a value very close to starting viscosity (initial viscosity). This behavior is repeatable, i.e., if the solution was sheared again the viscosity of the solution increased.

However, the magnitude of the viscosity showed dependency of preshear history and geometry of the viscometer. Dynamic measurement of the **surfactant** solution provided evidence that this solution is viscoelastic. The fully developed **friction** factors for viscoelastic **surfactant** solns. were in fair agreement with the results for water and viscoelastic polymer solution in the laminar flow region, and with viscoelastic polymer solns. in the turbulent flow region.

ACCESSION NUMBER: 1999:414991 HCAPLUS  
DOCUMENT NUMBER: 131:103926  
TITLE: Experimental study of the rheological and **heat transfer** behavior of an aqueous **surfactant** solution (1st report-rheological study)  
AUTHOR(S): Ishiguro, Suguru  
CORPORATE SOURCE: Department of Mechanical Engineering, University of Illinois at Chicago, IL, 60607-7074, USA  
SOURCE: Thermal Science and Engineering (1999), 7(2), 13-20  
CODEN: TSENGR; ISSN: 0918-9963  
PUBLISHER: Nippon Dennetsu Gakkai  
DOCUMENT TYPE: Journal  
LANGUAGE: English  
REFERENCE COUNT: 17 THERE ARE 17 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

L8 ANSWER 18 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB A method for reducing **friction drag** of aqueous **heat-transfer** medium in the pipeline comprises adding as high-d. heat transport **surfactants** amine oxides having the general formula  $R_1R_2R_3NO$ , where  $R_1$ ,  $R_2$  and  $R_3$  are specific diolefin, polyolefin and acetylenic hydrocarbonyl groups, and/or contain alkyl ether groups containing ethylene oxide, propylene oxide, butylene oxide or their mixts. Proper sizes of **micelles** can be formed, especially at the concentration of amine oxides of 0.05-1.0 weight% in aqueous solns.

ACCESSION NUMBER: 1998:728450 HCAPLUS  
DOCUMENT NUMBER: 130:54712  
TITLE: Method for reducing **friction drag** of aqueous **heat-transfer** medium in the pipeline  
INVENTOR(S): Nakada, Itaru; Nagai, Jotaro; Nobuchika, Kazuo  
PATENT ASSIGNEE(S): Toho Chemical Industry Co., Ltd., Japan  
SOURCE: Jpn. Kokai Tokkyo Koho, 7 pp.  
CODEN: JKXXAF  
DOCUMENT TYPE: Patent  
LANGUAGE: Japanese  
FAMILY ACC. NUM. COUNT: 1  
PATENT INFORMATION:

PATENT NO.	KIND	DATE	APPLICATION NO.	DATE
JP 10298585	A2	19981110	JP 1997-122875	19970428
PRIORITY APPLN. INFO.:			JP 1997-122875	19970428

L8 ANSWER 19 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN

AN 1998(19):94765 ENERGY

AB Surfactant additives can reduce the turbulent drag during the transportation of fluids through a pipe. The drag-reducing effectiveness of several surfactants with different molecular structure were tested. Experimental data of drag reduction evaluation led to the following. The carbon-carbon double bond in a hydrophobic group of cat-ionic surfactant is effective to improve the drag reduction effectiveness in the lower

temperature range. Introduction of a hydroxyethyl group into the hydrophilic part gives the same effect. The length of alkyl or alkylene group of a cationic surfactants is not the necessary uniform so as to give an effective drag reduction. A cationic surfactant with an ether group in a hydrophobic group is effective to change the strength of the micelles. Also, it is found that a non-ionic surfactant (some kind of amine oxide compound) can be the used as a good drag reducer without counter ion. 9 refs., 4 figs., 2 tabs.

TITLE: Effect of surfactant molecular structure on turbulent drag reduction.  
Ranryu teiko gensho koka ni oyobosu kaimen kasseizai no bunshi kozo no eikyo.  
AUTHOR: Usui, H. (Kobe Univ. (Japan). Faculty of Engineering); Saeki, T. (Yamaguchi Univ., Ube (Japan). Faculty of Engineering); Wakui, F. (Lion Corp. Tokyo (Japan))  
SOURCE: Kagaku Kogaku Ronbunshu (Jan 1998) v. 24(1) p. 134-137.  
CODEN: KKRBAW ISSN: 0386-216X  
DOCUMENT TYPE: Journal  
COUNTRY: Japan  
LANGUAGE: Japanese  
FIELD AVAILABILITY: AB

L8 ANSWER 20 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB The **heat transfer** of turbulence flow for **drag**-reducing **surfactant** aqueous solution in a two-dimensional channel was investigated exptl. Wire mesh plug was inserted into the channel to take the role of destroying **micelle** structure temporarily so as to enhance **heat transfer** for **surfactant** solution. The thermal entrance region for **surfactant** solution was found longer than that of water case. For the solution with **surfactant** concentration ranges from 30ppm to 90ppm there were no significant differences found in **heat transfer** performance in the channel without plug. The critical Reynolds number increases with the increasing of **surfactant** solution. A dependency of the variation trend of Nusselt number vs. Reynolds number to the channel's height was proposed to be utilized in the designing of **heat exchangers** using **surfactant** solution. It was found that when there was wire mesh plug inserted in the channel, the **surfactant** concentration influenced the **heat transfer** significantly. If the flow Reynolds number is close to the critical Reynolds number, the **heat transfer** of turbulence **surfactant** solution can be enhanced more efficiently using wire mesh plug. A LDV measurement of turbulence structure for the flow after mesh was conducted. The mesh plug was found play a role to destroy **micelle** super structures and thus to re-introduce strong turbulence in the flow in case of enhancing **heat transfer** after mesh plug.

ACCESSION NUMBER: 1999:336003 HCAPLUS  
DOCUMENT NUMBER: 131:20807  
TITLE: Experimental investigation of **heat transfer** enhancement for turbulence **drag**-reducing flow in a two-dimensional channel  
AUTHOR(S): Li, P. W.; Daisaka, H.; Kawaguchi, Y.; Yabe, A.; Hishida, K.; Maeda, M.  
CORPORATE SOURCE: Mechanical Engineering Laboratory, AIST, MITI, Tsukuba, 305, Japan  
SOURCE: EF Conference in Turbulent Heat Transfer, 2nd, Manchester, UK, May 31-June 4, 1998 (1998), Volume 2, P/21-P/29. National Technical Information Service: Springfield, Va.  
CODEN: 67QLAY  
DOCUMENT TYPE: Conference  
LANGUAGE: English

REFERENCE COUNT: 15 THERE ARE 15 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

L8 ANSWER 21 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB Investigation of characteristics of cold water pipe flow with **surfactant** is important to develop a cold heat energy transport system. Both flow **drag** and **heat transfer** redns. by the Toms effect occur due to a rod-like **micelle** structure of **surfactant**. When a counter-ion (sodium salicylate) was added to water solution containing of dodecyltrimethylammonium chloride (DTAC) **surfactant** in the present study, the rod-like **micelle** structure of DTAC was formed by connection of spherical **micelle** of DTAC. Moreover, the reduction characteristics of flow resistance and **heat transfer** were influenced by the amount of the counter-ion. Useful nondimensional correlative equations for flow resistance and **heat transfer** are derived in terms of various nondimensional parameters.

ACCESSION NUMBER: 1997:378619 HCAPLUS  
DOCUMENT NUMBER: 127:36451  
TITLE: Flow resistance and **heat transfer** characteristics of cold water pipe flow with **surfactant** for cold heat energy transport  
AUTHOR(S): Inaba, Hideo; Haruki, Naoto  
CORPORATE SOURCE: Japan  
SOURCE: Nippon Kikai Gakkai Ronbunshu, B-hen (1997), 63(608), 1336-1343  
CODEN: NKGBDD; ISSN: 0387-5016  
PUBLISHER: Nippon Kikai Gakkai  
DOCUMENT TYPE: Journal  
LANGUAGE: Japanese

L8 ANSWER 22 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB In order to clarify the mechanism of turbulent **heat transfer** in **drag** reducing flow by **surfactant** additives, temperature in the thermal boundary layer in a two dimensional channel has been exptl. investigated. Time-averaged mean temperature and temperature fluctuations were examined at a Reynolds number of  $1.2 \times 10^4$  using a fine wire thermocouple probe. The **surfactant** system tested was CTAC/NaSal/water. A high diffusivity layer near the wall was found in the thermal boundary layer of the **surfactant** solution. The layer is formed by **micellar** phase change. Time scales of the temperature fluctuation in the **surfactant** solution flow became large compared to the water flow. This suggests the role of the fluid elasticity is to suppress the coherent structure near the wall. As the **drag** reducing additives have a direct effect on the flow structure in the buffer layer at  $10 < y^+ < 100$ , redns. of **drag** and **heat transfer** are not recovered nevertheless in the high diffusivity layer.

ACCESSION NUMBER: 1998:318499 HCAPLUS  
DOCUMENT NUMBER: 128:296363  
TITLE: Study on a thermal boundary layer of **drag** reducing **surfactant** solution - measurements of temperature fluctuation  
AUTHOR(S): Kawaguchi, Y.; Daisaka, H.; Li, P. W.; Yabe, A.; Hishida, K.; Maeda, M.  
CORPORATE SOURCE: Mechanical Engineering Laboratory, Agency of Industrial Science and Technology, MITI, Tsukuba, Japan  
SOURCE: FED (1997), 244(Proceedings of the ASME Fluids Engineering Division, 1997), 375-380  
CODEN: FEDSDL; ISSN: 0888-8116  
PUBLISHER: American Society of Mechanical Engineers  
DOCUMENT TYPE: Journal

LANGUAGE: English  
REFERENCE COUNT: 16 THERE ARE 16 CITED REFERENCES AVAILABLE FOR THIS  
RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

L8 ANSWER 23 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN

AN 1997(17):108431 ENERGY

AB Investigation of characteristics of cold water pipe flow with surfactant is important to develop a cold heat energy transport system. Both flow drag and heat transfer reductions by the Toms effect occur due to a rod-like micell structure of surfactant. When a counter-ion (sodium salicylate) was added to water solution containing of dodecyltrimethylammonium chloride (DTAC) surfactant in the present study, the rod-like micell structure of DTAC was formed by connection of spherical micells of DTAC. Moreover, the reduction characteristics of flow resistance and heat transfer were influenced by the amount of the counter-ion. Useful nondimensional correlative equations for flow resistance and heat transfer are derived in terms of various nondimensional parameters. 8 refs., 16 figs.

TITLE: Flow resistance and heat transfer characteristics of cold water pipe flow with surfactant for cold heat energy transport.

Reinetsu energy yusoyo kaimen kasseizai tenka teionsui no kannai ryudo teiko to netsudentatsu tokusei.

AUTHOR: Inaba, H.; Haruki, N. (Okayama University, Okayama (Japan). Faculty of Engineering)

SOURCE: Nippon Kikai Gakkai Ronbunshu. B Hen (Transactions of the Japan Society of Mechanical Engineers. Part B) (25 Apr 1997) v. 63(608) p. 208-215.  
CODEN: NKGBDD ISSN: 0387-5016

DOCUMENT TYPE: Journal

COUNTRY: Japan

LANGUAGE: Japanese

FIELD AVAILABILITY: AB

L8 ANSWER 24 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN

AN 1997(16):100126 ENERGY

AB The continuously running liquid film tunnel is a novel device suitable for the study of two-dimensional flows. In this innovation, the films start from a reservoir, run over a horizontal or non-horizontal wire frame and get pulled/washed by a water sheet or by gravity of liquid film. However, despite the simple design and widespread application of LFT, its working mechanisms are not well understood. In the present work, an experimental effort for explaining these mechanisms is reported. The results show that both film velocities and film flow rates increase with water sheet velocity up to a saturation level. This behavior is described via a force balance between the shear force produced by the water sheet and the opposing pulling force of reservoir and boundary layer frictions. The results also show that the average film thickness depends on the surfactant concentration. This is as predicted by a model based on Langmuir's adsorption theory, in which the liquid film contains two external monolayers of surfactant and a slab of surfactant solution in between. When a film is drawn from the reservoir to the water sheet, the surfactant molecules start migrating from the former to the latter. To restore the thermodynamic equilibrium, the dragged film pulls more surfactant due to Marangoni elasticity, and thus a flow is established. The film flow soon reaches an equilibrium rate as required by the force balance mentioned above. (orig.). With 18 figs.

TITLE: Fundamentals of a liquid (soap) film tunnel.

AUTHOR: Beizaie, M. (California Univ., San Diego, La Jolla, CA (United States). Dept. of Applied Mechanics and Engineering Science); Gharib, M. (Graduate Aeronautical Laboratory, California Institute of Technology, 1200 California Boulevard, Pasadena, CA 91125 (United States))

SOURCE: Experiments in Fluids (13 Jun 1997) v. 23(2) p. 130-140.  
CODEN: EXFLDU ISSN: 0723-4864  
DOCUMENT TYPE: Journal  
COUNTRY: Germany, Federal Republic of  
LANGUAGE: English  
FIELD AVAILABILITY: AB

L8 ANSWER 25 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB The redns. in **friction** and **heat transfer** exhibited by a **surfactant** solution in the entry region of a circular pipe were measured and analyzed, with special attention paid to the relationship between the local **heat transfer** and **friction**. Two entrance configurations were used, a cone contraction and wire mesh plugs used as a device for velocity profile flattening. Both the simultaneous development of temperature and velocity profiles and the development of temperature profile with hydrodynamically predeveloped flow were studied. Interestingly, the local **heat transfer** measurements for **surfactant** solns. matched very well a correlation developed for polymer solns., but for **surfactants** the development of the **heat transfer** and velocity profiles appear coupled, unlike what is thought to happen for polymer solns. The development patterns appear to be independent of velocity and entrance type at low disturbance levels. At high disturbance levels, however, some striking changes in the fluid itself, likely due to temporary **micellar** structure degradation by high local shear stress in the inlet region, were observed as well, and quantified.

ACCESSION NUMBER: 1997:200577 HCAPLUS

DOCUMENT NUMBER: 126:227010

TITLE: Experimental investigation of thermal and hydrodynamic development regions for **drag-reducing surfactant** solutions

AUTHOR(S): Gasljevic, K.; Matthys, E. F.

CORPORATE SOURCE: Department of Mechanical and Environmental Engineering, University of California, Santa Barbara, CA, 93106, USA

SOURCE: Journal of Heat Transfer (1997), 119(1), 80-88

CODEN: JHTRAO; ISSN: 0022-1481

PUBLISHER: American Society of Mechanical Engineers

DOCUMENT TYPE: Journal

LANGUAGE: English

L8 ANSWER 26 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB Use is made of a mixture of  $\geq 1$  alkanolamide  $RCONH(A)nH$  ( $R$  = hydrocarbon group having 7-23 C atoms, preferably 11-23 C atoms,  $A$  = an alkyleneoxy group having 2-4 C atoms and  $n = 2-12$ , preferably 2-8), and  $\geq 1$  ionic **surfactant** in a proportion between the alkoxyated alkanolamide and the ionic **surfactant** from 100-1:2 in hard water circulation systems (cold or hot) such as **heat exchangers**. The ionic **surfactant** can be anionic, cationic, amphoteric or zwitterionic. A test solution was prepared from a mixture of C8-18 fatty acid amide of ethoxylated (3 and 4 mol EO) ethanolamine 1.45, and 1.45, resp., and lauryl ether sulfate 1.10 kg/m<sup>3</sup>.

ACCESSION NUMBER: 1996:369919 HCAPLUS

DOCUMENT NUMBER: 125:36334

TITLE: Use of alkoxyated alkanolamide together with an ionic **surfactant** as **friction-reducing agent**

INVENTOR(S): Hellsten, Martin; Harwigsson, Ian; Brink, Carina

PATENT ASSIGNEE(S): Akzo Nobel Nv, Neth.

SOURCE: PCT Int. Appl., 17 pp.

CODEN: PIXXD2

DOCUMENT TYPE: Patent

LANGUAGE: English



FAMILY ACC. NUM. COUNT: 1  
PATENT INFORMATION:

PATENT NO.	KIND	DATE	APPLICATION NO.	DATE
WO 9610616	A1	19960411	WO 1995-SE1081	19950922
W: CA, JP, US				
RW: AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE				
SE 9403363	A	19960404	SE 1994-3363	19941003
SE 503485	C2	19960624		
EP 784658	A1	19970723	EP 1995-934368	19950922
EP 784658	B1	20021120		
R: BE, DE, ES, FR, GB, IT, NL				
JP 10506663	T2	19980630	JP 1995-511664	19950922
ES 2182913	T3	20030316	ES 1995-934368	19950922
US 5911236	A	19990615	US 1997-809639	19970326
PRIORITY APPLN. INFO.:			SE 1994-3363	A 19941003
			WO 1995-SE1081	W 19950922
OTHER SOURCE(S):			MARPAT 125:36334	

L8 ANSWER 27 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB **Drag** reduction in a flowing liquid by threadlike **surfactant micelles** has the advantage over other elongated structures in that a mech. disruption, e.g. by a pump, will not be permanent, i.e. the **micelles** are self-healing. The time for relaxation of the **micelles** may be long enough to justify a mech. disturbance immediately before a **heat exchanger** in order to minimize the reduction in **heat transfer** caused by the **drag** reducing **surfactant**, which in this case consisted of an N-alkylbetaine and Na-dodecyl-benzenesulfonate.

ACCESSION NUMBER: 1996:591267 HCAPLUS

DOCUMENT NUMBER: 125:251509

TITLE: **Drag** reduction in district heating and cooling circuits-temporary disruption of **micelles** to preserve the **heat exchanger** capacity.

AUTHOR(S): Blais, C.; Harwigsson, I.; Hellsten, M.; Wollerstrand, J.

CORPORATE SOURCE: Natural Resources Canada/CANMET, Can.

SOURCE: World Surfactants Congress, 4th, Barcelona, June 3-7, 1996 (1996), Volume 2, 424-438. Asociacion Espanola de Productores de Sustancias para Aplicaciones Tensioactivas: Barcelona, Spain.  
CODEN: 63KCAH

DOCUMENT TYPE: Conference

LANGUAGE: English

L8 ANSWER 28 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB The application of **drag** reducing additives is a promising technol. to improve the operation of district heating-systems. With small amts. of cationic **surfactants** in district heating and cooling water the pressure drop in pipelines can be reduced significantly. Due to this effect the pump energy of existing district heating systems can be decreased or the flow rate can be raised clearly. In addition, the supply temperature of district heating systems can be decreased significantly when keeping the heat output constant. New networks can be designed with smaller pipe diams. or the maximum economic transmission length can be increased by applying **drag** reducing additives. The cationic **surfactants** form rod like **micelle** above a critical concentration CMC II. Under a certain shear stress the **micelles** align up in the direction of the flow and built the so called shear induced state (SIS). This SIS leads to a damping of radial turbulence and therefore, to a reduction in pressure loss. In addition to the pos. effect of **drag** reduction, some neg. effects occur, due to the change in flow behavior. These

are influences on **heat exchangers**, heat meters, pumps, filters, etc. The most important problem is a **heat transfer** reduction in **heat exchangers** which can be 95% in pipes of shell and tube apparatus. Up to now, most of the influences have been investigated in laboratory and full scale tests. Concerning the application in district heating and cooling systems measures have to be carried out to compensate for significantly neg. effects. Considering the supply guarantee as most important requirement the influence on **heat exchangers** has to be given particular attention. In this paper exptl. and theor. results are reported which have been got in several research projects carried out in Germany.

ACCESSION NUMBER: 1998:330672 HCAPLUS  
DOCUMENT NUMBER: 129:55951  
TITLE: Application of **drag** reducing additives in district heating systems  
AUTHOR(S): Steiff, Artur; Kloppe, Karsten  
CORPORATE SOURCE: Department of Chemical Engineering, University of Dortmund, Dortmund, Germany  
SOURCE: FED (1996), 237(Proceedings of the ASME Fluids Engineering Division Summer Meeting--1996, Vol. 2), 235-242  
CODEN: FEDSDL; ISSN: 0888-8116  
PUBLISHER: American Society of Mechanical Engineers  
DOCUMENT TYPE: Journal  
LANGUAGE: English  
REFERENCE COUNT: 8 THERE ARE 8 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

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L8 ANSWER 29 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB N-stearyl- and N-cetylbetaines show good **drag** reducing properties when they are combined with 20-30% of Na-dodecylbenzenesulfonate, and the salt content of the water is low. The products are readily biodegraded and the water solution may thus be disposed of by normal sewage treatment. The **heat transfer** in **heat exchangers** will normally be reduced by **drag** reducing additives, but this detrimental effect can be significantly decreased by a suitable disturbance of the **micellar** structure immediately before the **heat exchanger**.

ACCESSION NUMBER: 1998:330648 HCAPLUS  
DOCUMENT NUMBER: 129:55950  
TITLE: **Drag** reduction by N-alkylbetaines - a type of zwitterionic **surfactants**  
AUTHOR(S): Hellsten, Martin; Harwigsson, Ian; Blais, Caroline; Wollerstrand, Janusz  
CORPORATE SOURCE: Central Research and Development, Akzo Nobel Surface Chemistry AB, Stenungsund, Swed.  
SOURCE: FED (1996), 237(Proceedings of the ASME Fluids Engineering Division Summer Meeting--1996, Vol. 2), 37-46  
CODEN: FEDSDL; ISSN: 0888-8116  
PUBLISHER: American Society of Mechanical Engineers  
DOCUMENT TYPE: Journal  
LANGUAGE: English  
REFERENCE COUNT: 15 THERE ARE 15 CITED REFERENCES AVAILABLE FOR THIS RECORD. ALL CITATIONS AVAILABLE IN THE RE FORMAT

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L8 ANSWER 30 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN  
AB Amphoteric **surfactants** containing one or more, preferably one or two, monovalent hydrophobic groups forming a hydrophobic portion containing 10-36 carbon atoms; one or more, preferably one or two, primary, secondary or tertiary amine groups; and one or more, preferably one or two, carboxylic groups; and having a mol. weight of <1400, or a salt thereof, as a **friction** reducing agent in a water-based liquid system were found have a **friction** reducing effect when added to

water-based liquid system like heat transfer system.

ACCESSION NUMBER: 1995:774638 HCAPLUS  
DOCUMENT NUMBER: 123:174731  
TITLE: Use of an amphoteric surfactant as a  
friction-reducing agent  
INVENTOR(S): Hellsten, Martin; Harwigsson, Ian  
PATENT ASSIGNEE(S): Berol Nobel AB, Swed.  
SOURCE: PCT Int. Appl., 17 pp.  
CODEN: PIXXD2  
DOCUMENT TYPE: Patent  
LANGUAGE: English  
FAMILY ACC. NUM. COUNT: 1  
PATENT INFORMATION:

PATENT NO.	KIND	DATE	APPLICATION NO.	DATE
WO 9511288	A1	19950427	WO 1994-EP3431	19941017
W: CA, CN, CZ, EE, FI, HU, JP, LT, LV, NO, PL, RU, US				
RW: AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE				
SE 9303458	A	19941003	SE 1993-3458	19931021
SE 500923	C2	19941003		
CA 2171558	AA	19950427	CA 1994-2171558	19941017
EP 728173	A1	19960828	EP 1994-930189	19941017
EP 728173	B1	19990107		
R: AT, DE, DK, ES, FR, GB, IT, NL, SE				
AT 175437	E	19990115	AT 1994-930189	19941017
ES 2128589	T3	19990516	ES 1994-930189	19941017
US 5700766	A	19971223	US 1996-632461	19960419
PRIORITY APPLN. INFO.:			SE 1993-3458	A 19931021
			WO 1994-EP3431	W 19941017
OTHER SOURCE(S):		MARPAT 123:174731		

L8 ANSWER 31 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN  
AN 1996(22):156532 ENERGY  
AB In district heating systems the costs of heat distribution play a  
decisive rule. Most of the pumping energy is expended on pressure losses  
in transport pipes. Drag reducing additives offer a new technology which  
can substantially reduce pressure losses in pipe systems and therefore  
can lead to a reduction of the transport costs. In 1992 an EU/BMFT  
(European Union, German Ministry for Research and Technology)  
demonstration project on the application of drag reducing additives in a  
real district heating system was started. (orig./KO)  
TITLE: Long-time application of drag reducing additives in  
the district heating system of Voelklingen-Luisenthal.  
Langzeiteinsatz von Reibungsminderern im  
Fernwaermenetz Voelklingen-Luisenthal.  
AUTHOR: Kloepper, K. (Lehrstuhl fuer Thermische  
Verfahrenstechnik, Univ. Dortmund (Germany)); Althaus,  
W. (Institut fuer Umwelt-, Energie- und  
Sicherheitstechnik e.V. (Umsicht), Oberhausen  
(Germany)); Wefels, P. (Saarberg Fernwaerme GmbH,  
Saarbruecken (Germany)); Besch, H. (Saarberg  
Fernwaerme GmbH, Saarbruecken (Germany))  
SOURCE: District Heating International (Jun 1995) v. 24(6) p.  
267-276.  
CODEN: DHINEV ISSN: 0933-6540  
DOCUMENT TYPE: Journal  
COUNTRY: Germany, Federal Republic of  
LANGUAGE: German  
FIELD AVAILABILITY: AB; ABDE

L8 ANSWER 32 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN  
AN 1993(20):126322 ENERGY  
AB Technologies which may reduce the capital investment and/or operating

costs of district heating and cooling systems are reviewed. One method of reducing the cost of the district cooling distribution system is to reduce the pipe diameters while maintaining the capacity of the cooling fluid. This can be accomplished using ice slurries, which can provide 120 MJ/m<sup>3</sup> of water for a typical operating temperature differential of 7 degree C. Compared to conventional chilled water for district cooling, ice slurry systems offer the advantage of smaller distribution pipes, circulating pumps, and heat exchangers. In addition, since the ice slurry supply water is near the freezing point, less air volume is required to handle the cooling load in a building, thus fans and their motors can be smaller. Another way to reduce district cooling system costs is to increase the difference between the water entering and leaving the building cooling systems. For both district heating and cooling systems, the use of friction reducing additives which suppress turbulence in fluid flow can reduce frictional losses in the distribution system by up to 80%. The result is an increase in energy carrying capacity and/or a reduction in operating power costs. For new systems, the capital cost of pipes, fittings, and pumps will be lower. Types of additives include high molecular weight linear polymers, large aspect ratio fibres and filaments, and surfactants. Increasing the velocities in the distribution system can also increase the energy carrying capacity, although larger pumps must be used and more complex measures are required to reduce the severity of certain hydraulic problems. A potential application for higher velocities is in the design of the distribution system for peak load hours. 10 refs.

TITLE: Advanced technology studies, City of Toronto district heating and cooling. Appendix 1.  
CORPORATE SOURCE: MacViro Consultants, Inc., Markham, ON (Canada)  
NUMBER OF CONTRACT: EMR 23440-1-9072-01-SQ  
NUMBER OF REPORT: MVC--3171-10; MICROLOG--93-01564  
SOURCE: Feb 1991. 10 p. PC Canada Centre for Mineral and Energy Technology, Technical Information Division, 562 Booth St., Room 20-C, Ottawa, ON, CAN K1A 0G1; MF CANMET/TID, Energy, Mines and Resources Canada, 555 Booth St., Ottawa, Ont., Canada K1A 0G1 PC PRICES UPON REQUEST; MF \$10 CAN.  
DOCUMENT TYPE: Report; Availability Note  
COUNTRY: Canada  
LANGUAGE: English  
FIELD AVAILABILITY: AB

L8 ANSWER 33 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN  
AN 1991(9):52796 ENERGY

AB The phenomenon of drag reduction is, that by adding a small amount of cationic surfactant to water both the radial and axial fluctuations of velocity are decreased, so that the pressure drop is diminished. At the same time heat transfer is reduced because of the decreasing radial fluctuations of velocity. New developed cationic surfactants, which molecules assemble into rodlike aggregates (micelles), are suited for application in district heating systems as drag reducers. One important question of economics is the influencing of heat transfer and pressure drop in typical heat exchangers by using drag reducing surfactants. In the paper heat transfer and pressure drop of aqueous solutions of surfactants are investigated in tubes. In consideration of the flow behaviour, which is described in literature, the main topic of the work is the evaluation of an equation for heat transfer of aqueous solutions of surfactants. (orig.).

TITLE: Heat transfer and pressure drop of aqueous solutions of surfactants in tubes.  
Waermeuebergang und Druckverlust waesseriger Tensidloesungen in Rohren.  
AUTHOR: Weber, M. (Huels AG, (Germany, F.R.)); Steiff, A.; Weinspach, P.M. (Dortmund Univ. (Germany, F.R.)).  
Lehrstuhl fuer Thermische Verfahrenstechnik)

SOURCE: Forschung im Ingenieurwesen (Germany, F.R.) (1991) v. 57(1) p. 1-7.  
CODEN: FIGWA5 ISSN: 0015-7899  
DOCUMENT TYPE: Journal  
COUNTRY: Germany, Federal Republic of  
LANGUAGE: German  
FIELD AVAILABILITY: AB; ABDE

L8 ANSWER 34 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN

AN 1989(13):84459 ENERGY

AB Friction reducing additive scale-up experiments were carried out with 200 wppm Separan solution and 2000 wppm Kemamine solution in a test section with a nominal pipe diameter of 6.0 inches and a length of 70 feet. The experimental results of pressure drop tests of Separan and Kemamine indicate that the friction reduction is not affected by pipe size when the solution is fresh. However, short-term degradation tests show that the high molecular weight polymer solution degrades completely due to the high pump shear and aging, while the surfactant solution does not lose its friction reduction effectiveness because of the high pump shear and appears to have a long lifetime. 9 refs., 8 figs.

TITLE: Friction-reducing additive scale-up experiments in a pilot-scale DHC system simulator.

AUTHOR: Choi, U.S.; Kasza, K.E.; Liu, K.V. [United States]

CORPORATE SOURCE: Argonne National Lab., IL (USA)

NUMBER OF CONTRACT: W-31109-ENG-38

NUMBER OF REPORT: CONF-890624--1; DE89013287

SOURCE: May 1989. 12 p. Availability: NTIS, PC A03/MF A01 - OSTI; 1.; GPO Dep. Portions of this document are illegible in microfiche products.  
Conference: 80. annual conference of the International District Heating and Cooling Association, Virginia Beach, VA, USA, 18 Jun 1989

DOCUMENT TYPE: Report; Conference

COUNTRY: United States

LANGUAGE: English

L8 ANSWER 35 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN

AN 1986(22):176413 ENERGY

AB Results of heat transfer and pressure drop measurements are presented for the turbulent flow of aqueous solutions of drag reducing additives. The drag reducing effect was caused by adding small amounts of high-molecular polymers or special cationic surfactants to the solvent. The experimental results show that for both types of additives the measured heat transfer reduction (up to 94%) is always greater than the drag reduction (up to 84%). By increasing temperature both, the mechanical and the thermal degradation of the polymers increase. At temperatures exceeding 90 deg C polymeric drag reducers are no more applicable in closed loops. The drag reducing surfactants have a critical temperature and a critical shear stress above which the heat transfer and the friction coefficients rapidly return to those of the pure solvent. However, unlike in polymeric solutions, this process is reversible. The effectiveness of the surfactants is absolutely stable below the critical data. Both, a higher critical temperature and shear stress is obtainable by changing the concentration of the surfactant. In this study a stable drag and heat transfer reduction could be obtained up to temperatures of 145 deg C at relevant mechanical strain. With these results the application of drag reducing surfactants in district heating systems seems to be practicable. With 72 refs., 3 tabs., 36 figs.

TITLE: Influence of drag reducing additives on pressure drop and heat transfer in district heating systems. Final report.

Zum Einfluss von Reibungsminderern auf den Druckverlust und den Waermeuebergang in Fernwaermeleitungen. Schlussbericht.

AUTHOR: Wellinghoff, G. [Germany, Federal Republic of]  
CORPORATE SOURCE: Bundesministerium fuer Forschung und Technologie, Bonn  
(Germany, F.R.)  
NUMBER OF REPORT: BMFT-FB-T--86-058; DE86753235  
Jul 1986. 129 p. Availability: NTIS (US Sales Only),  
PC A07/MF A01.  
DOCUMENT TYPE: Report  
COUNTRY: Germany, Federal Republic of  
LANGUAGE: German

L8 ANSWER 36 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB The effect was studied of the **micelle** size on the hydrodynamic resistance of **surfactant** solns. used in heat carriers as **drag** reducing agents. The reduction of the hydrodynamic resistance is dependent on the parameters of **micelle**-forming substance in the solution. The effective size of **micelles** for reducing the resistance is 37-45  $\mu$ .

ACCESSION NUMBER: 1985:134163 HCAPLUS

DOCUMENT NUMBER: 102:134163

TITLE: Effect of **micelle** size on the hydrodynamic resistance of a **heat-transfer** agent

AUTHOR(S): Karashchenko, V. N.; Zaitseva, S. E.

CORPORATE SOURCE: USSR

SOURCE: Vestnik L'vovskogo Politekhnicheskogo Instituta  
(1984), 184, 63-6

CODEN: VLPIAZ; ISSN: 0460-0436

DOCUMENT TYPE: Journal

LANGUAGE: Russian

L8 ANSWER 37 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB A review of 89 references is given for the polymers effective in **drag** reduction. High levels of **drag** reduction may be obtained in H<sub>2</sub>O for short times with only a few ppm. high-**mol.**-weight poly(ethylene oxide). Na carboxymethyl cellulose, hydroxyethyl cellulose, guar gum, and some polyacrylamides yield high **drag** reduction. Polyisobutylene solns. in PhMe and poly(Me methacrylate) have **drag** -reducing properties. Aqueous polyacrylic acid, carboxymethyl-hydroxyethyl cellulose solution, and polystyrene solution in PhMe do not exhibit **drag** reduction. The effects of **mol.** characteristics on **drag** reduction, the shear degradation of polymers in solution, soap solution **drag** reduction, solid suspension **drag** reduction mechanism, the **heat transfer** to **drag**-reducing fluids, and the designing for **drag** reduction are discussed.

ACCESSION NUMBER: 1969:38538 HCAPLUS

DOCUMENT NUMBER: 70:38538

TITLE: **Drag** reduction. Polymer solutions, soap solutions, and solid particle suspensions in pipe flow  
AUTHOR(S): Patterson, Gary K.; Zakin, Jacques L.; Rodriguez, Jorge M.

CORPORATE SOURCE: Univ. of Missouri, Rolla, MO, USA

SOURCE: Industrial and Engineering Chemistry (1969), 61(1),  
22-30

CODEN: IECHAD; ISSN: 0019-7866

DOCUMENT TYPE: Journal; General Review

LANGUAGE: English

L8 ANSWER 38 OF 39 HCAPLUS COPYRIGHT 2004 ACS on STN

AB The addition of some **surface-active** substances to liquids reduced resistance to flow due to **friction** of the liquid vs. a solid (e.g., 20% in the case of water containing phenol flowing through tubes of glass, Cu, or Al). Coating of the surface of a solid with solid lyophobic films (e.g., coating with polyethylhydroxysiloxane of the wall of a tube through which flow of water took place), while not affecting

wall **friction** resistance to flow, altered significantly the lower critical Reynolds number,  $Re$ , reducing it from 2300 to 1750 (i.e., transition from laminar to turbulent flow was facilitated). The rate of **heat transfer** was also affected: in expts. in which a film of polyethylsiloxane had been applied, the rate of **heat transfer** was reduced at  $Re < 104$  and increased at  $Re > 104$ . Addition to water of polymeric **surface-active** agents of the stabilizer type lowered the coefficient of **friction** of water against the wall in flow through tubes. Thus, addition of the Na salt of carboxymethyl cellulose (I) to water flowing through a glass tube reduced the coefficient of **friction** by 20-40% at  $Re > 104$ . A latent period of 15-20 min. was required before this effect could take place, because orientation of **mols.** of the **surface-active** agent adsorbed on the tube wall was necessary. The reduction of the coefficient of **friction** in flow through a tube on which I had been adsorbed was retained after the I solution had been replaced with distilled  $H_2O$  and the latter flowed through the tube. The coefficient of **friction** was increased at low values of  $Re$  and also on application of vibrations.

ACCESSION NUMBER: 1966:33302 HCAPLUS  
DOCUMENT NUMBER: 64:33302  
ORIGINAL REFERENCE NO.: 64:6119c-e  
TITLE: Effect of surface phenomena on transfer processes  
AUTHOR(S): El'perin, I. T.; Smol'skii, B. M.  
SOURCE: Vestsi Akad. Navuk Belarusk. SSR, Ser. Fiz.-Tekhn. Navuk (1965), (2), 39-44  
DOCUMENT TYPE: Journal  
LANGUAGE: Belorussian

L8 ANSWER 39 OF 39 ENERGY COPYRIGHT 2004 USDOE/IEA-ETDE on STN  
AN 1992(18):134952 ENERGY

AB While investment costs may be reduced by, e.g. novel, cheaper piping methods operating expenses decrease as one improves the utilization of distributing pipes. In both cases frictional resistance and heat transfer factors may be reduced by adding small quantities of a suitable additive to the water which passes the district heating pipes. Under certain conditions (temperature, flow velocity, geometry) such additives reduce the fluid flow's frictional pressure drop and the heat transfer between flowing medium and pipe wall. The study investigates the frictional-resistance- and heat-transfer-reducing properties of different tenside-based substances, the so-called micellar friction-reducing agents. The experimental results are entered in a mathematical model which provides a first calculation basis for prediction of the performance of district heating networks treated with substances which reduce the frictional resistance. (orig./Cd).

TITLE: Pressure drop and heat transfer in district heat pipelines when tensides are added. Final report. Druckverlust und Waermeuebergang in Fernwaermeleitungen bei Zugabe von Reibungsminderern. Abschlussbericht.

AUTHOR: Weinspach, P.M.  
CORPORATE SOURCE: Deutsche Gesellschaft fuer Luft- und Raumfahrt e.V. (Germany); Bundesministerium fuer Forschung und Technologie, Bonn (Germany)

NUMBER OF CONTRACT: BMFT 0328710C  
SOURCE: [1992]. 115 p. Available from FIZ Karlsruhe.  
DOCUMENT TYPE: Miscellaneous; Availability Note  
COUNTRY: Germany  
LANGUAGE: German  
FIELD AVAILABILITY: AB; ABDE

Set	Items	Description
S1	385056	(HEAT? OR THERM?) ( ) (EXCHANG? OR TRANSFER?)
S2	175540	SURFACTANT? OR SURFACE( ) ACTIVE OR SURFACEACTIVE( ) AGENT?
S3	653570	ANION? OR CATION? OR COUNTERION? OR NONION? OR (AN OR CAT - OR COUNTER OR NON) ( ) (ION OR IONS OR IONIC?) OR TEMPERATURE( ) I- NDEPENDENT OR (NON OR "NOT") ( ) TEMPERATURE( ) DEPENDENT
S4	3505239	MOLECUL? OR MICELL? OR MICROSTRUCTUR? OR MICRO( ) STRUCTUR?
S5	355629	DRAG OR FRICTION?
S6	1360786	WIRE? OR MESH?? OR FILTER??
S7	1620859	REBUIL? OR RECOVER? OR RECONSTITUT? OR RECOMPOS? OR REFORM? OR REPAIR? OR REPAR? OR SELFREPAIR? OR REASSEMBL? OR SELFASS- EMBL? OR SELF( ) (REPAR? OR ASSEMBL? OR REPAIR?)
S8	4398118	BREAK? OR FRACTUR? OR DISRUPT? OR TURBULEN? OR DEGRAD? OR - DISTURB? OR ROIL? OR STRESS? OR SHEAR?
S9	764458	BREAK?( ) UP OR ENLIVEN? OR INVIGORAT? OR FOAM? OR FROTH? OR EDDY? OR SWIRL? OR VORTEX? OR VORTIC? OR HELIX? OR HELIC?
S10	1959114	PUMP? OR VALV? OR FLOW( ) GEOMET? OR TEMPERATURE( ) JUMP? OR H- YDRODYNAM? OR HYDRON? OR ULTRASONIC? OR ULTRASOUND? OR ELECTR- OMAGNET?
S11	1059	S1 AND S2
S12	161	S11 AND S3
S13	1059	S11:S12
S14	164	S13 AND S4
S15	255	S13 AND S5
S16	67	S14 AND S15
S17	352	S14:S15
S18	25	S17 AND S6
S19	6	S17 AND S7(5N)S4
S20	16	S17 AND S7 AND S4
S21	217	S17 AND S8:S10
S22	82	S21 AND S4
S23	106	S16 OR S18:S20 OR S22
S24	49	S23 AND PY<2000
S25	44	RD (unique items)

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25/3,K/6 (Item 1 from file: 94)

DIALOG(R)File 94:JICST-EPlus

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04404147 JICST ACCESSION NUMBER: 99A0798522 FILE SEGMENT: JICST-E

Drag reduction by surfactant additives and its applications.

KAWAGUCHI YASUO (1)

(1) Mech. Eng. Lab., Agency of Ind. Sci. and Technol.

Hyomen, Hyomen Danwakai, Koroido Konwakai, 1999 , VOL.37,NO.8,

PAGE.443-450, FIG.9, REF.32

JOURNAL NUMBER: G0745AAK ISSN NO: 0367-648X

UNIVERSAL DECIMAL CLASSIFICATION: 544.77.022.532 532.135:544.77

LANGUAGE: Japanese COUNTRY OF PUBLICATION: Japan

DOCUMENT TYPE: Journal

ARTICLE TYPE: Review article

MEDIA TYPE: Printed Publication

Drag reduction by surfactant additives and its applications.

, 1999

DESCRIPTORS: surfactant ; ...

...fluid friction ; ...

... turbulent diffusion...

... micelle effect...

... heat transfer coefficient

...BROADER DESCRIPTORS: friction ;

25/3,K/7 (Item 2 from file: 94)  
DIALOG(R)File 94:JICST-EPlus  
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04207927 JICST ACCESSION NUMBER: 99A0570309 FILE SEGMENT: JICST-E  
**The Similarity between Heat and Mass Transfer across the Wind-Driven  
Air-Water Interface.**

SHIMADA TAKASHI (1); KOMORI SATORU (1)  
(1) Kyoto Univ., Grad. Sch.  
Nippon Kikai Gakkai Ronbunshu. B(Transactions of the Japan Society of  
Mechanical Engineers. B), 1999 , VOL.65,NO.634, PAGE.2092-2098, FIG.6,  
TBL.1, REF.14

JOURNAL NUMBER: F0036BAN ISSN NO: 0387-5016  
UNIVERSAL DECIMAL CLASSIFICATION: 551.511  
LANGUAGE: Japanese COUNTRY OF PUBLICATION: Japan  
DOCUMENT TYPE: Journal  
ARTICLE TYPE: Original paper  
MEDIA TYPE: Printed Publication

, 1999  
...ABSTRACT: eddies controlling heat and mass transfer is independent of  
the liquid kinematic viscosity. Furthermore, the **heat transfer**  
coefficient on the liquid side was measured for the air-water interface  
in the wind...  
...can be seen in the high wind speed region where the effects of the tiny  
**surface - active** impurities on the **molecular** diffusivity at the  
interface are removed by intense wave- **breaking** . However, the  
similarity disappears in the lower wind speed region, The damping  
effect of the **surface - active** impurities on the **heat transfer** is  
larger than that on the mass transfer. (author abst.)  
DESCRIPTORS: **turbulent heat transfer ; ...**

... surfactant ; ...

... **heat transfer** coefficient  
BROADER DESCRIPTORS: convective **heat transfer ; ...**

... **heat transfer ;**

25/3,K/8 (Item 3 from file: 94)

DIALOG(R) File 94:JICST-EPlus

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04184114 JICST ACCESSION NUMBER: 99A0437715 FILE SEGMENT: JICST-E  
**Experimental Study of the Rheological and Heat Transfer Behavior of an  
Aqueous Surfactant Solution. 1st Report. Rheological Study.**

ISHIGURO S (1)

(1) Univ. Illinois At Chicago, Il, Usa

Therm Sci Eng, 1999 , VOL.7,NO.2, PAGE.13-20, FIG.8, REF.17

JOURNAL NUMBER: L1615AAS ISSN NO: 0918-9963

UNIVERSAL DECIMAL CLASSIFICATION: 532.13 536.25/.3

LANGUAGE: English COUNTRY OF PUBLICATION: Japan

DOCUMENT TYPE: Journal

ARTICLE TYPE: Original paper

MEDIA TYPE: Printed Publication

**Experimental Study of the Rheological and Heat Transfer Behavior of an  
Aqueous Surfactant Solution. 1st Report. Rheological Study.**  
, 1999

DESCRIPTORS: frictional resistance...

... surfactant ; ...

... micelle ; ...

... shear rate...

... heat transfer ;

BROADER DESCRIPTORS: drag ; ...

... hydrodynamic force

25/3,K/9 (Item 4 from file: 94)  
DIALOG(R)File 94:JICST-EPlus  
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03649076 JICST ACCESSION NUMBER: 98A0698838 FILE SEGMENT: JICST-E  
**The Study on Heat Transfer of Surfactant Solution as Drag -Reducing Flow.**

LI P-W (1); KAWAGUCHI Y (1); YABE A (1); DAISAKA H (2); HISHIDA K (2);  
MAEDA M (2)  
(1) AIST, MITI, Tsukuba; (2) Keio Univ., Yokohama  
Nippon Dennetsu Shinpojiumu Koen Ronbunshu, 1998 , VOL.35th,NO.Vol.3,  
PAGE.691-692, FIG.5, REF.2

JOURNAL NUMBER: F0872CAE

UNIVERSAL DECIMAL CLASSIFICATION: 628.81/.84+697 532.542

LANGUAGE: English COUNTRY OF PUBLICATION: Japan

DOCUMENT TYPE: Conference Proceeding

ARTICLE TYPE: Short Communication

MEDIA TYPE: Printed Publication

**The Study on Heat Transfer of Surfactant Solution as Drag -Reducing Flow.**

, 1998

ABSTRACT: In order to use **surfactant** aqueous solution in district heating and cooling system as **drag** -reducing flow. Methods to enhance its **heat transfer** were investigated through a two-dimensional channel. **Wire mesh** plug was found can take the role of destroying **micelle** structure temporarily in **drag** -reducing flow for **heat transfer** enhancement. The variation trend of **heat transfer** with Reynolds number in two-dimensional channel was found in different with different channel height for **surfactant** solution. To arrange the channel height and Reynolds number properly the **surfactant** solution will be **drag** -reducing flow in the fluid transportation section and be **turbulence** water flow in **heat transfer** section. (author abst.)

...DESCRIPTORS: **frictional** resistance...

... **surfactant** ; ...

... **heat transfer** coefficient

...BROADER DESCRIPTORS: **drag** ; ...

... **hydrodynamic** force

25/3,K/10 (Item 5 from file: 94)  
DIALOG(R)File 94:JICST-EPlus  
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03144409 JICST ACCESSION NUMBER: 97A0522368 FILE SEGMENT: JICST-E  
**Flow Resistance and Heat Transfer Characteristics of Cold Water Pipe  
Flow with Surfactant for Cold Heat Energy Transport.**

INABA HIDEO (1); HARUKI NAOTO (2)

(1) Okayama Univ., Fac. of Eng.; (2) Okayama Univ., Grad. Sch.  
Nippon Kikai Gakkai Ronbunshu. B(Transactions of the Japan Society of  
Mechanical Engineers. B), 1997, VOL.63,NO.608, PAGE.1336-1343,  
FIG.16, REF.8

JOURNAL NUMBER: F0036BAN ISSN NO: 0387-5016  
UNIVERSAL DECIMAL CLASSIFICATION: 536.25/.3 621.6  
LANGUAGE: Japanese COUNTRY OF PUBLICATION: Japan  
DOCUMENT TYPE: Journal  
ARTICLE TYPE: Original paper  
MEDIA TYPE: Printed Publication

**Flow Resistance and Heat Transfer Characteristics of Cold Water Pipe  
Flow with Surfactant for Cold Heat Energy Transport.**  
, 1997

ABSTRACT: Investigation of characteristics of cold water pipe flow with  
**surfactant** is important to develop a cold heat energy transport  
system. Both flow **drag** and **heat transfer** reductions by the Toms  
effect occur due to a rod-like **micell** structure of **surfactant**. When  
a **counter - ion** (sodium salicylate) was added to water solution  
containing of dodecyltrimethylammonium chloride(DTAC) **surfactant** in  
the present study, the rod-like **micell** structure of DTAC was formed  
by connection of spherical **micells** of DTAC. Moreover, the reduction  
characteristics of flow resistance and **heat transfer** were  
influenced by the amount of the **counter - ion**. Useful nondimensional  
correlative equations for flow resistance and **heat transfer** are  
derived in terms of various nondimensional parameters. (author abst.)

...DESCRIPTORS: convective **heat transfer** ; ...

... **surfactant** ; ...

...tube **friction** ;

...BROADER DESCRIPTORS: **heat transfer** ; ...

...fluid **friction** ; ...

... **friction**

25/3,K/11 (Item 6 from file: 94)  
DIALOG(R)File 94:JICST-EPlus  
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02800509 JICST ACCESSION NUMBER: 96A0597434 FILE SEGMENT: JICST-E  
Flow Drag and Heat Transfer of Low Temperature Water Solution Pipe  
Flow with Surfactant .

INABA HIDEO (1); HARUKI NAOTO (2)  
(1) Okayama Univ., Fac. of Eng.; (2) Okayama Univ., Grad. Sch.  
Nippon Dennetsu Shinpojiumu Koen Ronbunshu, 1996 , VOL.33rd,NO.Vol 2,  
PAGE.577-578, FIG.4, REF.4

JOURNAL NUMBER: F0872CAE  
UNIVERSAL DECIMAL CLASSIFICATION: 628.81/.84+697  
LANGUAGE: Japanese COUNTRY OF PUBLICATION: Japan  
DOCUMENT TYPE: Conference Proceeding  
ARTICLE TYPE: Short Communication  
MEDIA TYPE: Printed Publication

Flow Drag and Heat Transfer of Low Temperature Water Solution Pipe  
Flow with Surfactant .  
, 1996

ABSTRACT: This paper deals with the reduction characteristics of flow resistance and **heat transfer** of water solution with nucleating **surfactant** for low temperature energy transport. This flow **drag** reduction is explained by Toms effect, which is caused by a **surfactant micell** structure. This study focuses on Dodecyltrimethylammonium Chloride (DTAC,  $C_{12}H_{25}N(CH_3)_3Cl=263.89$ ) as a **surfactant** . And, Sodium Salicylate ( $C_7H_5NaO_3=160.10$ ) adds to the water solution with DTAC for a **surfactant micell** structure formation. The reduction characteristics of flow resistance and **heat transfer** of the DTAC solution are investigated. (author abst.)

DESCRIPTORS: **surfactant** ; ...

... **counter ion** effect...

... **heat transfer coefficient**...

... **frictional resistance**

...BROADER DESCRIPTORS: **drag** ; ...

... **hydrodynamic force**

25/3,K/13 (Item 8 from file: 94)  
DIALOG(R) File 94:JICST-EPlus  
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02601566 JICST ACCESSION NUMBER: 96A0012878 FILE SEGMENT: JICST-E  
**Flow Resistance Characteristics of Low Temperature Surfactant Aqueous  
Solution in Circular Tubes.**

INABA HIDEO (1); HARUKI NAOTO (2)

(1) Okayama Univ., Fac. of Eng.; (2) Okayama Univ., Grad. Sch.

Nippon Kikai Gakkai Netsu Kogaku Bumon Koenkai Koen Ronbunshu, 1995 ,

VOL.1995, PAGE.152-153, FIG.4, REF.4

JOURNAL NUMBER: L0417AAX

UNIVERSAL DECIMAL CLASSIFICATION: 536.25/.3

LANGUAGE: Japanese COUNTRY OF PUBLICATION: Japan

DOCUMENT TYPE: Conference Proceeding

ARTICLE TYPE: Short Communication

MEDIA TYPE: Printed Publication

**Flow Resistance Characteristics of Low Temperature Surfactant Aqueous  
Solution in Circular Tubes.**

, 1995

ABSTRACT: This paper describes the reduction characteristics of flow resistance and **heat transfer** of water solution with nucleating **surfactant** for low temperature energy transport. This flow **drag** reduction is explained by Toms effect, which is caused by a **surfactant micell** structure. This study focuses on Dodecyltrimethylammonium Chloride (DTAC,  $C_{12}H_{25}N(CH_3)_3Cl=263.89$ ) as a **surfactant**. And, Sodium Salicylate ( $C_7H_5NaO_3=160.10$ ) adds to the water solution with DTAC for a **surfactant micell** structure. Viscosity of the DTAC solution is measured. The useful correlation equation of viscosity for...

...terms of temperature and concentration ratio of DTAC. The reduction characteristics of flow resistance and **heat transfer** of the DTAC solution are investigated. (author abst.)

...DESCRIPTORS: tube **friction** ; ...

...convective **heat transfer** ; ...

... **cationic surfactant** ;

...BROADER DESCRIPTORS: fluid **friction** ; ...

... **friction** ; ...

... **heat transfer** ; ...

... **surfactant** ;



25/3,K/14 (Item 9 from file: 94)  
DIALOG(R)File 94:JICST-EPlus  
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02389199 JICST ACCESSION NUMBER: 95A0758314 FILE SEGMENT: JICST-E  
**Viscosity Measurements of CTAC:NaSal/W Micelle Solution Temperature  
Effect and Wall Effect of Viscometer.**

KAWAGUCHI YASUO (1); TANAKA MAKOTO (1); TAWARAYA YOSHISATO (2)  
(1) Mech. Eng. Lab., Agency of Ind. Sci. and Technol.; (2) Grad. Sch., Keio Univ.

Kikai Gijutsu Kenkyujo Shoho(Journal of Mechanical Engineering Laboratory)  
, 1995 , VOL.49,NO.4, PAGE.172-181, FIG.8, TBL.2, REF.18

JOURNAL NUMBER: F0150ABK ISSN NO: 0388-4252

UNIVERSAL DECIMAL CLASSIFICATION: 66.045.1 628.81+697.1/.7

LANGUAGE: Japanese COUNTRY OF PUBLICATION: Japan

DOCUMENT TYPE: Journal

ARTICLE TYPE: Original paper

MEDIA TYPE: Printed Publication

**Viscosity Measurements of CTAC:NaSal/W Micelle Solution Temperature  
Effect and Wall Effect of Viscometer.**  
, 1995

ABSTRACT: Apparent viscosity is measured for **micelles** from cetyltrimethyl ammonium chloride in aqueous solution using cylindrical Couette viscometer. Authors are making basic...

...the purpose of improving district heating/cooling system by using of such a kind of **drag** reducing **surfactant** as the working fluid. In this report, parameters relating to **heat exchanger** i.e. effect of **surfactant** solution temperature, slit width of viscometer and surface material of viscometer were experimentally investigated. As...

...the complicated effect of temperature to apparent viscosity. Due to the non-Newtonian feature of **surfactant** solution, apparent viscosity is a function of **shear** rate. At the same time, it was found that apparent viscosity was affected by slit width and solid surface material of viscometer. Improvement of **heat exchanger** is suggested on the basis of these characteristics of **surfactant micelle** solution. (author abst.)

DESCRIPTORS: **heat exchanger** ; ...

... **cationic surfactant** ; ...

...fluid **friction** ; ...

... **micelle** formation...

...critical **micelle** concentration

...BROADER DESCRIPTORS: **surfactant** ; ...

... **friction** ;

25/3,K/15 (Item 10 from file: 94)  
DIALOG(R)File 94:JICST-EPlus  
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02254136 JICST ACCESSION NUMBER: 94A0941397 FILE SEGMENT: JICST-E  
Measurement of viscosity of quaternary ammonium salt water solution as a  
drag reducing fluid.

KAWAGUCHI YASUO (1); TANAKA MAKOTO (1); KUM S-M (1)  
(1) Mech. Eng. Lab., Agency of Ind. Sci. and Technol.  
Thermophys Prop, 1994, VOL.15th, PAGE.247-250, FIG.5, REF.8  
JOURNAL NUMBER: X0031AAB ISSN NO: 0911-1743  
UNIVERSAL DECIMAL CLASSIFICATION: 66.021.2  
LANGUAGE: Japanese COUNTRY OF PUBLICATION: Japan  
DOCUMENT TYPE: Conference Proceeding  
ARTICLE TYPE: Original paper  
MEDIA TYPE: Printed Publication

Measurement of viscosity of quaternary ammonium salt water solution as a  
drag reducing fluid.  
1994

...ABSTRACT: study on conserving energy of fluid transportation in the  
district heating/cooling system by using **surfactant** solution as the  
working fluid. It is reported that the **drag** reduction is expected for  
**surfactant** solution but the amount of **drag** reduction is largely  
affected by Reynolds number, concentration of **surfactant** and  
temperature. Therefore, measurement of viscosity, which has close  
relation to the mechanism of **drag** reduction is necessary to design  
optimum **drag** reduction in fluid transportation pipe line or **heat**  
**exchangers** in district heating/cooling system. In this study, viscosity  
of Cethyltrimethyl ammonium chloride(CTAC) quaternary...

...Experimental parameters were the clearance  $d$  between the inner cylinder  
and outer one of viscometer, **shear** rate  $D$ , concentration  $C$  of CTAC in  
water and temperature  $T$  of CTAC aqueous solution...

...2. It is seen that  $\mu_{\alpha}$  has dependency both on  $D$  and  $d$ ,  
therefore, **surfactant** solution has characteristic scales of **shear**  
and length even in laminar state.  $\mu_{\alpha}$  and  $D$  relationship obeys  
power law fluid described by equation(1). In addition to the  
thixotropic time dependency, **surfactant** solution has special feature,  
which is called **shear** induced state(SIS). Figure 3 shows time record  
of viscometer output when **shear** rate was kept constant. After few  
minutes of **shear** starting, increase of  $\mu_{\alpha}$  which corresponds  
to transition to SIS is observed. Such a...

...suggests that, in flow field,  $\mu_{\alpha}$  must be described not only by  
the local **shear** rate but also by convection term which contains the  
information of history of dynamics imposed...

DESCRIPTORS: fluid **friction** ; ...

... **frictional** resistance...

... **cationic** **surfactant** ; ...

... **micelle**

BROADER DESCRIPTORS: **friction** ; ...

... **drag** ; ...

... **hydrodynamic** force...

... surfactant ;

25/3,K/17 (Item 12 from file: 94)  
DIALOG(R)File 94:JICST-EPlus  
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01769663 JICST ACCESSION NUMBER: 93A0276678 FILE SEGMENT: JICST-E  
Drag reduction and heat transfer reduction by cationic surfactants

USUI H (1); SAEKI T (1)

(1) Yamaguchi Univ.

J Chem Eng Jpn, 1993 , VOL.26,NO.1, PAGE.103-106, FIG.4, REF.12

JOURNAL NUMBER: S0629AAN ISSN NO: 0021-9592 CODEN: JCEJA

UNIVERSAL DECIMAL CLASSIFICATION: 628.81/.84+697 66.021.4

LANGUAGE: English COUNTRY OF PUBLICATION: Japan

DOCUMENT TYPE: Journal

ARTICLE TYPE: Original paper

MEDIA TYPE: Printed Publication

Drag reduction and heat transfer reduction by cationic surfactants

, 1993

ABSTRACT: Drag reduction effects of quaternary ammonium salt cationic surfactants were examined and it was confirmed the formation of rod micelle was effective for both drag reduction and decrease in thermal resistance. Decrease in thermal resistance was more effective for energy saving than drag reduction. It is necessary to continue the search of more adequate surface active agents in future. Examination of energy saving by surfactants in district cooling and heating system based on the experimental results proved that this sytem

DESCRIPTORS: cationic surfactant ; ...

... drag ; ...

... heat transfer ; ...

... micelle ;

BROADER DESCRIPTORS: surfactant ; ...

... hydrodynamic force

25/3,K/18 (Item 1 from file: 95)  
DIALOG(R)File 95:TEME-Technology & Management  
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01139841 M97091286670

**Experimental investigation of thermal and hydrodynamic development regions for drag -reducing surfactant solutions**

(Experimentelle Untersuchung der thermischen und hydrodynamischen Entwicklung von Rohrstroemungen mit widerstandsreduzierenden oberflaechenaktiven Zusaetzen)

Gasljevic, K; Matthys, EF

Univ. of California, Santa Barbara, USA

Transactions of the ASME, Journal of Heat Transfer, v119, n1, pp80-88, 1997

Document type: journal article Language: English

Record type: Abstract

ISSN: 0022-1481

**Experimental investigation of thermal and hydrodynamic development regions for drag -reducing surfactant solutions**

(Experimentelle Untersuchung der thermischen und hydrodynamischen Entwicklung von Rohrstroemungen mit widerstandsreduzierenden oberflaechenaktiven Zusaetzen)

1997

**ABSTRACT:**

The reductions in **friction** and **heat transfer** exhibited by a **surfactant** solution in the entry region of a circular pipe were measured and analyzed, with special attention paid to the relationship between the local **heat transfer** and **friction**. Two entrance configurations were used, a cone contraction and **wire mesh** plugs used as a device for velocity profile flattening. Both the simultaneous development of temperature and velocity profiles and the development of temperature profile with **hydrodynamically** predeveloped flow were studied.

Interestingly, the focal **heat transfer** measurements for **surfactant** solutions matched very well a correlation developed for Polymer solutions, but for **surfactants** the development of the **heat transfer** and velocity profiles appear coupled unlike what is thought to happen for polymer solutions. The development patterns appear to be independent of velocity and entrance type at low **disturbance** levels. At high **disturbance** levels, however, some striking changes in the fluid itself; likely due to temporary **micellar** structure **degradation** by high local **shear stress** in the inlet region, were observed as well, and quantified.

DESCRIPTORS: DETERGENT; PIPE FLOW; HEAT TRANSMISSION; HEAT DISTRIBUTION; VELOCITY DISTRIBUTION; FLOW VELOCITY; POLYMERS; COEFFICIENT OF **FRICTION**; NUSSELT NUMBER; CONICITY; **WIRE** LATTICE; EXPERIMENTAL STUDY

25/3,K/19 (Item 1 from file: 35)  
DIALOG(R)File 35:Dissertation Abs Online  
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01672818 ORDER NO: AADNQ-31534

**A STUDY OF DRAG REDUCTION AND CONVECTIVE HEAT TRANSFER REDUCTION IN  
TURBULENT FLOW THROUGH PIPES**

Author: SOOD, ARUN

Degree: PH.D.

Year: 1997

Corporate Source/Institution: DALHOUSIE UNIVERSITY (CANADA) (0328)

Source: VOLUME 59/10-B OF DISSERTATION ABSTRACTS INTERNATIONAL.

PAGE 5478. 183 PAGES

ISBN: 0-612-31534-7

**A STUDY OF DRAG REDUCTION AND CONVECTIVE HEAT TRANSFER REDUCTION IN  
TURBULENT FLOW THROUGH PIPES**

Year: 1997

Addition of a small quantity of certain long chain polymers or **micelle** forming **surfactant** additives to a fluid will cause the **frictional drag** and convective **heat transfer** to be reduced in **turbulent** pipe flow. Reynolds number has been proven to be inadequate for characterizing the flow of such **drag** reducing solutions in different diameter pipes.

The reduction in **drag** and convective **heat transfer** occurs due to dampening of the velocity fluctuations in the **turbulent** boundary layer. Velocity fluctuations close to the wall are dependent upon **shear stress**, and are independent of the pipe diameter. Consequently, reduction in **drag** and **heat transfer**, calculated at a constant **shear stress**, should also be independent of the pipe diameter. The above hypothesis was successfully tested on polymer-oil and **surfactant** -water systems.

Dampening of velocity fluctuations results in thickening of the laminar sublayer and can also be equated to a reduction in Prandtl's mixing length. Velocity- **shear stress** data generated by flow experiments in a laboratory scale pipe along with viscosity measurements enable...

...the modified mixing length constant and the thickness of the laminar sublayer for a given **drag** reducing fluid, which can be subsequently used for predicting flow and **heat transfer** in any diameter pipe. The above methodology was successfully used for predicting **drag** reduction scale-up for **surfactant** -water and polymer-oil systems and **heat transfer** reduction for **surfactant** -water and polymer-water systems. The Model predictions were compared with other models available in published literature.

The use of **drag** reducing **surfactant** additives in heating or cooling systems causes an unwanted reduction in convective **heat transfer** in **heat exchangers**. This adverse effect can be overcome by intentionally **breaking** the **heat transfer** reducing **surfactant micelles** at the inlet to the **heat exchanger**. The **micelles** would **recover** further downstream and regain their **drag** reducing properties. A preliminary experimental investigation was conducted to study **micellar break - up** and **recovery** in a pipe. It was observed that the **recovery** length of **micelles** for a given bulk velocity was constant and was independent of pressure drop across the **shearing** device. A methodology, which assumes the test pipe to be a plug flow reactor, has been presented for calculating the **recovery** time of **micelles**.

25/3,K/20 (Item 2 from file: 35)  
DIALOG(R)File 35:Dissertation Abs Online  
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01500993 ORDER NO: AAD96-26867

**EXPERIMENTAL STUDY OF THE RHEOLOGICAL AND HEAT TRANSFER BEHAVIOR OF AN  
AQUEOUS SURFACTANT SOLUTION (RECTANGULAR DUCT, LAMINAR FLOW, TURBULENCE  
)**

Author: ISHIGURO, SUGURU

Degree: PH.D.

Year: 1996

Corporate Source/Institution: UNIVERSITY OF ILLINOIS AT CHICAGO (0799)

Source: VOLUME 57/04-B OF DISSERTATION ABSTRACTS INTERNATIONAL.

PAGE 2823. 244 PAGES

**EXPERIMENTAL STUDY OF THE RHEOLOGICAL AND HEAT TRANSFER BEHAVIOR OF AN  
AQUEOUS SURFACTANT SOLUTION (RECTANGULAR DUCT, LAMINAR FLOW, TURBULENCE  
)**

Year: 1996

Heat transfer and pressure drop measurements of a viscoelastic surface active agent ( surfactant ) solution have been carried out in a 2:1 aspect ratio rectangular duct under laminar and turbulent conditions.

Viscosity measurements of the surfactant solution showed that the apparent viscosity increased when sheared at a fixed shear rate. This behavior is due to the microstructure change of the micelles ( shear -induced-structure or SIS).

For laminar flow of the surfactant solution through the duct, the heat transfer results showed some enhancement due to the secondary flows but not as large as observed for the polymer solution.

For turbulent flow friction factors and Nusselt numbers of the surfactant solution through the duct showed the substantial reduction from the Newtonian fluid results, being about 75% in friction factors and about 87% in Nusselt numbers. No degradation effects were observed.

25/3,K/27 (Item 2 from file: 6)

DIALOG(R)File 6:NTIS

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1697097 NTIS Accession Number: TIB/B92-03046

**Druckverlust und Waermeuebergang in Fernwaermeleitungen bei Zugabe von Reibungsminderern. Abschlussbericht. (Pressure drop and heat transfer in district heat pipelines when tensides are added. Final report)**

Weinspach, P.M.

Dortmund Univ. (Germany, F.R.). Lehrstuhl fuer Thermische Verfahrenstechnik.

Corp. Source Codes: 062214034; 9203464

Sponsor: Bundesministerium fuer Forschung und Technologie, Bonn (Germany).

1992 115p

Languages: German

Journal Announcement: GRAI9305

In German.

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NTIS Prices: PC E14

**Druckverlust und Waermeuebergang in Fernwaermeleitungen bei Zugabe von Reibungsminderern. Abschlussbericht. (Pressure drop and heat transfer in district heat pipelines when tensides are added. Final report)**

...methods operating expenses decrease as one improves the utilization of distributing pipes. In both cases **frictional** resistance and **heat transfer** factors may be reduced by adding small quantities of a suitable additive to the water...

... pipes. Under certain conditions (temperature, flow velocity, geometry) such additives reduce the fluid flow's **frictional** pressure drop and the **heat transfer** between flowing medium and pipe wall. The study investigates the **frictional** -resistance- and **heat - transfer** -reducing properties of different tenside-based substances, the so-called **micellar friction** -reducing agents. The experimental results are entered in a mathematical model which provides a first...

... for prediction of the performance of district heating networks treated with substances which reduce the **frictional** resistance. (orig./Cd). (Copyright (c) 1992 by FIZ. Citation no. 92:003046.)

Descriptors: District heating; \*Pipelines; **Surfactants** ; Pressure drop; **Heat transfer** ; **Friction** factor; Additives; Viscosity; Reynolds number ; Isothermal processes; Stability; **Drag** ; Corrosion; Corrosion protection; Fluid flow



25/3,K/28 (Item 3 from file: 6)

DIALOG(R)File 6:NTIS

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1658152 NTIS Accession Number: TIB/B92-00892

**Waermeuebergang und Druckverlust waessriger Tensidloesungen in Rohren und Rohrwendeln.** (Heat transition and loss of pressure of dilute tenside dissolvings in pipes and pipe coils)

(Diss. (Dr.-Ing))

Weber, M.

Dortmund Univ. (Germany, F.R.). Fachbereich Chemietechnik.

Corp. Source Codes: 062214025; 9200627

1990 113p

Languages: German Document Type: Thesis

Journal Announcement: GRAI9217

In German.

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NTIS Prices: PC E14

... and sizes of the investigated pipe and pipe coils considered the availability of the special **cationic** tenside reducing the **friction** in long-range heating facilities. The heat transition and resistance reducing effect of the tensides is caused by the formation of special rod-shaped **micelles**, consisting of several tenside **molecules**. Finally, a simplified calculation concept, which was set up, yields informations about the reduced **heat exchanging** performance on an existing **heat exchanger** if a dilute tenside dissolving is used in the pipe coils. Different measures are presented and discussed by which the reduction of **heat exchanging** performance can be compensated. (orig./MZ). (Available from TIB Hannover: DW 1651.) (Copyright (c) 1992...

Descriptors: **Surfactants**; \*Rheology; **Heat transfer**; Pressure drop; Pipes; Fluid flow

25/3,K/30 (Item 5 from file: 6)

DIALOG(R)File 6:NTIS

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1282732 NTIS Accession Number: DE86753235

**Influence of Drag Reducing Additives on Pressure Drop and Heat Transfer in District Heating Systems. Final Report**

Wellinghoff, G.

Bundesministerium fuer Forschung und Technologie, Bonn (Germany, F.R.).

Corp. Source Codes: 057110000; 9200321

Report No.: BMFT-FB-T-86-058

Jul 86 129p

Languages: German

Journal Announcement: GRAI8708; NSA1100

In German.

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NTIS Prices: PC A07/MF A01

**Influence of Drag Reducing Additives on Pressure Drop and Heat Transfer in District Heating Systems. Final Report**

Results of heat transfer and pressure drop measurements are presented for the turbulent flow of aqueous solutions of drag reducing additives. The drag reducing effect was caused by adding small amounts of high-molecular polymers or special cationic surfactants to the solvent. The experimental results show that for both types of additives the measured heat transfer reduction (up to 94%) is always greater than the drag reduction (up to 84%). By increasing temperature both, the mechanical and the thermal degradation of the polymers increase. At temperatures exceeding 90 deg C polymeric drag reducers are no more applicable in closed loops. The drag reducing surfactants have a critical temperature and a critical shear stress above which the heat transfer and the friction coefficients rapidly return to those of the pure solvent. However, unlike in polymeric solutions, this process is reversible. The effectiveness of the surfactants is absolutely stable below the critical data. Both, a higher critical temperature and shear stress is obtainable by changing the concentration of the surfactant. In this study a stable drag and heat transfer reduction could be obtained up to temperatures of 145 sup 0 C at relevant mechanical strain. With these results the application of drag reducing surfactants in district heating systems seems to be practicable. With 72 refs., 3 tabs., 36 figs...

Descriptors: Turbulent Flow; \*District Heating; Additives; Chemical Composition; Flow Rate; Friction; Heat Exchangers; Heat Flux^; Heat Transfer; Measuring Methods; Micellar Systems; Microemulsion Flooding; Mockup; Polymers; Reynolds Number; Shear; Temperature Dependence

25/3,K/33 (Item 2 from file: 8)  
DIALOG(R) File 8: Ei Compendex(R)  
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05010670 E.I. No: EIP98054187441

**Title: Study on a thermal boundary layer of drag reducing surfactant solution - measurements of temperature fluctuation**

**Author:** Kawaguchi, Y.; Daisaka, H.; Li, P.W.; Yabe, A.; Hishida, K.; Maeda, M.

**Corporate Source:** Ministry of Int Trade and Industry, Tsukuba, Jpn

**Conference Title:** Proceedings of the 1997 ASME International Mechanical Engineering Congress and Exposition

**Conference Location:** Dallas, TX, USA **Conference Date:** 19971116-19971121

**E.I. Conference No.:** 47756

**Source:** ASME Fluids Engineering Division American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 244 1997. ASME, Fairfield, NJ, USA. p 375-380

**Publication Year:** 1997

**CODEN:** FEDSDL

**Language:** English

**Title: Study on a thermal boundary layer of drag reducing surfactant solution - measurements of temperature fluctuation**

**Abstract:** In order to clarify the mechanism of **turbulent heat transfer** in **drag** reducing flow by **surfactant** additives, temperature in thermal boundary layer in two dimensional channel has been experimentally investigated. Time...

...examined at the Reynolds number of 1.2 multiplied by  $10^{**4}$  using a fine **wire** thermocouple probe. The **surfactant** system tested was CTAC/NaSal/water. A high diffusivity layer near the wall was found in the thermal boundary layer of **surfactant** solution. The layer is formed by **micellar** phase change. Time scales of the temperature fluctuation in **surfactant** solution flow became large compared to the water flow. It suggests the role of the fluid elasticity to suppress the coherent structure near the wall. As the **drag** reducing additives have a direct effect on the flow structure in the buffer layer at  $10$  less than  $y^{**}$  plus less than  $100$ , reductions of **drag** and **heat transfer** are not **recovered** nevertheless of high diffusivity layer. (Author abstract) 16 Refs.

**Descriptors:** **Drag** ; Boundary layer flow; **Heat transfer** ; **Surface active** agents; Additives; Temperature measurement; Reynolds number; Thermocouples; Elasticity; **Turbulent** flow

25/3,K/34 (Item 3 from file: 8)  
DIALOG(R)File 8: Ei Compendex(R)  
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04661280 E.I. No: EIP97043590803

**Title:** Drag reduction by N-alkylbetaines - a type of zwitterionic surfactants

**Author:** Hellsten, Martin; Harwigsson, Ian; Blais, Caroline; Wollerstrand, Janusz

**Corporate Source:** Akzo Nobel Surface Chemistry AB, Stenungsund, Sweden

**Conference Title:** Proceedings of the 1996 ASME Fluids Engineering Division Summer Meeting. Part 2 (of 3)

**Conference Location:** San Diego, CA, USA **Conference Date:** 19960707-19960711

**E.I. Conference No.:** 46196

**Source:** American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 237 n 2 1996. ASME, New York, NY, USA. p 37-46

**Publication Year:** 1996

**CODEN:** FEDSDL

**Language:** English

**Title:** Drag reduction by N-alkylbetaines - a type of zwitterionic surfactants

**Abstract:** N-stearyl- and N-cetylbetaines show good drag reducing properties when they are combined with 20-30% of Na-dodecylbenzenesulphonate, and the salt...

...biodegraded and the water solution may thus be disposed of by normal sewage treatment. The heat transfer in heat exchangers will normally be reduced by drag reducing additives, but this detrimental effect can be significantly decreased by a suitable disturbance of the micellar structure immediately before the heat exchanger... (Author abstract) 15 Refs.

**Descriptors:** Surface active agents; Drag ; Heat transfer ; Heat exchangers^Additi ; Additives; Micelles ; Flow of fluids

**Identifiers:** Drag reduction; Stearylbetaines; Cetylbetaines; Sodium dodecylbenzenesulphonate; Shear induced structures; Zwitterionic surfactants

25/3,K/36 (Item 5 from file: 8)  
DIALOG(R) File 8: Ei Compendex(R)  
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04080787 E.I. No: EIP95022569369

Title: Hydrodynamic and thermal field development in the pipe entry region for turbulent flow of drag-reducing surfactant solutions

Author: Gasljevic, K.; Matthys, E.F.

Corporate Source: Univ of California, Santa Barbara, CA, USA

Conference Title: Proceedings of the 1994 International Mechanical Engineering Congress and Exposition

Conference Location: Chicago, IL, USA Conference Date: 19941106-19941111

E.I. Conference No.: 42353

Source: Developments in Non-Newtonian Flows American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED v 206 1994. ASME, New York, NY, USA. p 51-61

Publication Year: 1994

CODEN: FEDSDL

Language: English

Title: Hydrodynamic and thermal field development in the pipe entry region for turbulent flow of drag-reducing surfactant solutions

Abstract: The drag and heat transfer reductions induced by a surfactant solution in the entry region of a circular pipe were measured and analyzed, with special attention paid to the relationship between the local heat transfer and friction. Two entrance configurations were used: a cone contraction and a wire mesh plug used as a device for velocity profile flattening. Both the simultaneous development of temperature...

...also measured. A stronger coupling between the hydrodynamic and thermal field developments was observed for surfactant solutions than is generally believed to be the case for polymer solutions. (Author abstract) 13...

Descriptors: Turbulent flow; Hydrodynamics; Pipe flow; Heat transfer ; Drag ; Surface active agents ; Friction; Energy ; Energy dissipation; Temperature measurement; Velocity measurement

Identifiers: Drag reducing surfactant solutions; Temperature profiles ; Velocity profiles; Flow reorganization effects

25/3,K/37 (Item 6 from file: 8)  
DIALOG(R)File 8:EI Compendex(R)  
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03070709 E.I. Monthly No: EI9106066396

Title: **Waermeuebergang and Druckverlust waesseriger Tensidloesungen in Rohren.**

Title: **Heat transfer** and pressure drop of aqueous solutions of **surfactants** in tubes.

Author: Weber, Manfred; Steiff, Artur; Weinspach, Paul-Michael

Corporate Source: Huels AG, Marl, Ger

Source: Forschung im Ingenieurwesen v 57 n 1 Jan 1991 p 1-7

Publication Year: 1991

CODEN: FIGWA5 ISSN: 0015-7899

Language: German

Title: **Heat transfer** and pressure drop of aqueous solutions of **surfactants** in tubes.

Abstract: The phenomenon of **drag** reduction is, that by adding a small amount of **cationic surfactant** to water both the radial and axial fluctuations of velocity are decreased, so that the pressure drop is diminished. At the same time **heat transfer** is reduced because of the decreasing radial fluctuations of velocity. New developed **cationic surfactants**, which **molecules** assemble into rodlike aggregates (**micelles**), are suited for application in district heating systems as **drag** reducers. One important question of economics is the influencing of **heat transfer** and pressure drop in typical **heat exchangers** by using **drag** reducing **surfactants**. In the paper **heat transfer** and pressure drop of aqueous solutions of **surfactants** are investigated in tubes. In consideration of the flow behaviour, which is described in literature, the main topic of the work is the evaluation of an equation for **heat transfer** of aqueous solutions of **surfactants**. (Author abstract) 24 Refs. In German.

...Descriptors: **Drag** ; FLUID DYNAMICS...

... **Heat Exchangers** ; **HEAT EXCHANGERS** --...

...Efficiency; **HEAT TRANSFER** ; **TUBES**

Identifiers: **CATIONIC SURFACTANTS** ; **DRAG REDUCERS**; **VELOCITY FLUCTUATIONS**

25/3,K/39 (Item 1 from file: 34)  
DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

07966299 Genuine Article#: 230EU No. References: 25  
**Title:** Surfactant drag reduction in internally-grooved rough tubes  
**Author(s):** DeGuzman MR; Saeki T (REPRINT) ; Usui H; Nishimura T  
**Corporate Source:** YAMAGUCHI UNIV,DEPT CHEM ENGN & APPL CHEM/UBE/YAMAGUCHI  
7558611/JAPAN/ (REPRINT); YAMAGUCHI UNIV,DEPT CHEM ENGN & APPL  
CHEM/UBE/YAMAGUCHI 7558611/JAPAN/; KOBE UNIV,DEPT SCI & CHEM  
ENGN/KOBE/HYOGO 6778501/JAPAN/; YAMAGUCHI UNIV,DEPT MECH  
ENGN/UBE/YAMAGUCHI 7558611/JAPAN/  
**Journal:** JOURNAL OF CHEMICAL ENGINEERING OF JAPAN, 1999 , V32, N4 (AUG), P  
402-408  
**ISSN:** 0021-9592 **Publication date:** 19990800  
**Publisher:** SOC CHEMICAL ENG JAPAN, KYORITSU BUILDING 4-16-19 KOHINATA,  
BUNKYO KU TOKYO 112, JAPAN  
**Language:** English **Document Type:** ARTICLE (ABSTRACT AVAILABLE)

**Title:** Surfactant drag reduction in internally-grooved rough tubes  
, 1999

**Abstract:** It is well known that the use of certain **surfactants** and **counterions** can cause **drag** reduction in pipe flow. This phenomenon can be applied to a district heating and cooling system. In such a system, however, **heat transfer** reduction correspondingly occurs as **drag** reduction does. This should be a major problem as far as **heat transfer** application is concerned. In our study in this regard, we focused on **drag** reduction in practical **heat exchanger** tubes and determined the effect of **drag** reduction caused by a **surfactant** solution of Ethoquad O/12, We used three rough tubes with different groove pitches and...

...the effect of the roughness shape, From the results, we estimated the magnitude of the **heat transfer** reduction.  
...Identifiers--CETYLTRIMETHYLAMMONIUM BROMIDE; **MICELLES**; ADDITIVES;  
PIPES

25/3,K/42 (Item 4 from file: 34)  
DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

02955690 Genuine Article#: MR321 No. References: 21

Title: MEASUREMENT OF THE ORIENTATIONAL BINDING OF COUNTERIONS BY  
NUCLEAR-MAGNETIC-RESONANCE MEASUREMENTS TO PREDICT DRAG REDUCTION IN  
CATIONIC SURFACTANT MICELLE SOLUTIONS

Author(s): SMITH BC; CHOU LC; ZAKIN JL

Corporate Source: INT PAPER/MOBILE//AL/36652; BAKER PERFORMANCES CHEM  
INC/SAND SPRINGS//OK/74063; OHIO STATE UNIV,DEPT CHEM  
ENGN/COLUMBUS//OH/43210

Journal: JOURNAL OF RHEOLOGY, 1994 , V38, N1 (JAN-FEB), P73-83

ISSN: 0148-6055

Language: ENGLISH Document Type: ARTICLE (Abstract Available)

Title: MEASUREMENT OF THE ORIENTATIONAL BINDING OF COUNTERIONS BY  
NUCLEAR-MAGNETIC-RESONANCE MEASUREMENTS TO PREDICT DRAG REDUCTION IN  
CATIONIC SURFACTANT MICELLE SOLUTIONS  
, 1994

Abstract: Quaternary ammonium cationic surfactants with appropriate counterions are viscoelastic friction reducers and can reduce pumping energy requirements, increase water throughput, or reduce pump size Or pipeline diameter in closed loop district heating and cooling systems. Drag reduction occurs when rod-like micelles are present. Isomers of ortho-, meta-, and para-hydroxy-benzoate and chloro-benzoate were investigated by Fourier transform nuclear magnetic resonance (FT NMR). The orientation of each counterion near the micellar surface was inferred using the proton chemical shifts. NMR peak broadening was used to infer which counterions induce rod-like micellar aggregates and the occurrence of viscoelasticity. Drag reduction was only observed in the solutions which demonstrated peak broadening. The NMR chemical shift data indicate that only those counterions whose structure permits orienting their hydrophobic and hydrophilic portions in their preferred environments can stabilize the micellar interface to facilitate the sphere-to-rod transition and induce drag reduction. Thus, FT-NMR peak broadening and chemical shift data can be used to predict the drag-reducing capability of cationic surfactant - counterion systems.

Research Fronts: 92-5068 001 (COANNULAR JET FLOW; TURBULENT DRAG REDUCTION IN DILUTE POLYMER-SOLUTIONS; LASER DOPPLER VELOCIMETRY; SQUARE DUCT; MODEL BURNER; HEAT - TRANSFER BEHAVIOR)



25/3,K/44 (Item 1 from file: 65)  
DIALOG(R)File 65:Inside Conferences  
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01546335 INSIDE CONFERENCE ITEM ID: CN015353425

Drag reduction in district heating and cooling circuits. Temporary  
disruption of micelles to preserve the heat exchanger capacity  
Hellsten, M.; Blais, C.; Harwigsson, I.; Wollerstrand, J.  
CONFERENCE: World surfactants congress-4th (Fourth world surfactants  
congress)

SPECIAL PUBLICATION- ROYAL SOCIETY OF CHEMISTRY, 1996; VOL 188 P:  
424-438

Royal Society of Chemistry, 1996

ISSN: 0260-6291 ISBN: 0854047565

LANGUAGE: English DOCUMENT TYPE: Conference Papers

CONFERENCE LOCATION: Barcelona, Spain

CONFERENCE DATE: Jun 1996 (19960) (19960)

NOTE:

Theme title: "Approaching the 21st century"; In English, German and  
French

Drag reduction in district heating and cooling circuits. Temporary  
disruption of micelles to preserve the heat exchanger capacity  
Royal Society of Chemistry, 1996  
DESCRIPTORS: surfactants ; chemistry

Kozumplik, Joanne (ASRC)

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496349

**From:** STIC-ILL  
**Sent:** Tuesday, May 18, 2004 11:39 AM  
**To:** Kozumplik, Joanne (ASRC)  
**Subject:** FW: Article Request

-----Original Message-----

**From:** Solomon, Terrance  
**Sent:** Tuesday, May 18, 2004 11:31 AM  
**To:** STIC-ILL  
**Subject:** Article Request

For: Nihir Patel, 3743, 306-3463, pk1/11b43  
Case No: 09/786140  
Needs: **As soon as possible**

  
NPatel\_artreq.tif

DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
(c) 2004 Inst for Sci Info. All rts. reserv.

07279619 Genuine Article#: 145TX Number of References: 195  
Title: Surfactant drag reduction  
Author(s): Zakin JL; Bewersdorff HW  
Corporate Source: OHIO STATE UNIV,DEPT CHEM ENGN/COLUMBUS//OH/43210; FH  
LAUSITZ,DEPT CHEM ENGN/D-01968 SENFTENBERG//GERMANY/  
Journal: REVIEWS IN CHEMICAL ENGINEERING, 1998, V14, N4-5, P253-320  
ISSN: 0167-8299 Publication date: 19980000

ILL

MAY 18 2004

Kozumplik, Joanne (ASRC)


496348

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NPatel\_artreq.tif

DIALOG(R)File 34:SciSearch(R) Cited Ref Sci  
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07344114 Genuine Article#: 152VK Number of References: 43  
Title: Effect of variations in counterion to surfactant ratio on rheology  
and microstructures of drag reducing cationic surfactant systems  
Author(s): Lu B; Zheng Y; Davis HT; **Scriven LE**; Talmon Y; Zakin JL  
(REPRINT)  
Corporate Source: OHIO STATE UNIV,DEPT CHEM ENGN, 140 W 19TH  
AVE/COLUMBUS//OH/43210 (REPRINT); OHIO STATE UNIV,DEPT CHEM  
ENGN/COLUMBUS//OH/43210; UNIV MINNESOTA,DEPT CHEM ENGN & MAT  
SCI/MINNEAPOLIS//MN/55455; TECHNION ISRAEL INST TECHNOL,DEPT CHEM  
ENGN/IL-32000 HAIFA//ISRAEL/  
Journal: RHEOLOGICA ACTA, 1998, V37, N6 (DEC), P528-548  
ISSN: 0035-4511 Publication date: 19981200

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Rheol Acta 37:528-548 (1998)  
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# ORIGINAL CONTRIBUTION

Bin Lu  
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Jacques L. Zakin

## Effect of variations in counterion to surfactant ratio on rheology and microstructures of drag reducing cationic surfactant systems

Received: 13 April 1998  
Accepted: 29 July 1998

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**Abstract** Rheology, drag reduction and cryo-TEM experiments were performed on Arquad 16-50/NaSal and Ethoquad O/12/NaSal-surfactant systems at different counterion-to-surfactant ratios and at constant low surfactant concentrations, 3 mM, appropriate for drag reduction. The molar ratio of counterion-to-surfactant was varied from 0.6 to 2.5. All the surfactant systems described here are viscoelastic and drag reducing. The viscoelasticity and drag reducing effectiveness increase with increase in counterion/surfactant ratio. Network are present in the solutions with high ratio, and they are viscoelastic. However, shear is needed to induce network formation for solutions at low ratio. Cryo-TEM images confirm the existence of thread-like micelles which form entanglement networks, and show that the micellar network becomes denser with increasing counterion/

surfactant ratio in one surfactant series. Both increase in the counterion/surfactant ratio and increase in the shear rate result in shorter relaxation times.

For some of these systems, abrupt increase in viscosity is observed at certain shear rates which are time effects affecting microstructure rearrangements rather than formation of shear induced structures.

**Key words** Cationic surfactant rheology – counterion/surfactant ratio – surfactant drag reduction – cationic surfactant microstructure

### Introduction

Quaternary ammonium surfactants with certain counterions have been shown to be very effective drag reducers (White, 1967; Zakin et al., 1971; Rose et al., 1984, 1989; Elson and Garside, 1983; Ohlendorf et al., 1984, 1986a,b; Chou et al., 1989a,b; Chou, 1991). Surfactant molecules form micelles that are thread-like under conditions such as high concentrations or the presence of certain counterions. A number of authors have stated that the existence of thread-like micelles is necessary for surfactants to be drag-reducing. Variations in the

structure and quantity of the quaternary ammonium surfactant and the counterion have major effects on micellar structure (Lu et al., 1997a,b, 1998), on the effectiveness of the surfactant as a drag reducer (Chou, 1991; Smith et al., 1994a,b) and on the rheological properties (Ohlendorf et al., 1986a,b; Rehage et al., 1986; Bewersdorff and Ohlendorf, 1988; Bewersdorff, 1989, 1996; Lu et al., 1996a,b,c,d; Hu and Mathys, 1995, 1996; Lu et al., 1997a,b, 1998).

The chemical structure of the counterion and the ratio of its concentration to surfactant concentration are critical factors in determining if a cationic surfactant is effective

as a drag reducer. When the surfactant forms micelles, the positive charges of the head groups of cationic surfactants are closely packed on the micelle surface and tend to repel each other. Added negatively-charged counterions screen the positive charges of the cationic head groups and lead to thread-like micelle formation.

In the past decade a number of theoretical models for micelle formation and break-up have been proposed. Several of these are described in a recent paper by Koch (1997), who offered another model based on a thermodynamic model and hydrodynamic forces calculated with a rigid-dumbbell model.

The importance of counterion-to-surfactant ratio,  $\xi$ , has been noted by many researchers (Zakin et al., 1971; Rose et al., 1984, 1989; Chou et al., 1989b; Shikata et al., 1987, 1988a,b, 1990; Chou, 1991; Clausen et al., 1992; Smith, 1992; Lu et al., 1996b; Hu and Matthys, 1996). Early studies on additive/surfactant ratios by Zakin et al. (1971) indicated that for the 0.15% CTAB/1-naphthol system, the highest critical shear stress before micelle break-up occurs when the molar ratio of CTAB to 1-naphthol is 1 to 1 (weight ratio is 2.1:1). Shikata et al. (1990) studied the cetyltrimethylammonium bromide (CTAB) system with the addition of sodium salicylate. They found that the molar concentration of sodium salicylate has to equal that of the surfactant to dissociate all of the  $\text{Br}^-$  from the CTAB. Their results showed that the salicylate ion has a much stronger binding affinity to the surfactant than that of  $\text{Br}^-$ . Other studies showed that an excess of counterions may be needed for the best drag reduction performance. Rose et al. (1984) and Chou et al. (1989b) found that excess quantities of salicylate gave higher critical temperatures and higher critical Reynolds numbers (i.e., higher critical wall shear stress before mechanical degradation) for loss of drag reduction. The NMR results of Smith (1992) demonstrated how  $\xi$  affects micelle structure and viscoelasticity. However, it is still unclear how excess salicylate affects the drag reducing effectiveness of surfactant systems. In fact, even the location of the excess counterions in solutions is still not clear.

A large number of rheological and drag reduction studies on cationic surfactant systems have been reported. Generally, rheology investigators use high concentration for easy and better characterization of the systems, while drag reduction researchers work with the lowest possible concentrations to reduce the cost for applications. Information obtained in rheological studies on higher concentration surfactant systems is useful, but may not be directly applicable to drag reducing surfactant systems. In this paper, drag reduction, rheological and low temperature transmission electron microscope (cryo-TEM) studies on two surfactant systems with various counterion/surfactant ratios are presented. The effects of the ratio on microstructure and on viscoelasticity are discussed along with the effects on drag reduc-

tion. All measurements were made at low concentrations appropriate for drag reducing flows.

## Experimental

### Materials

The cationic surfactants used were Arquad 16-50 (cetyltrimethyl ammonium chloride,  $\text{C}_{16}\text{H}_{33}\text{N}(\text{CH}_3)_3\text{Cl}$ ) and Ethoquad O/12 (oleyl-methyldihydroxyethyl ammonium chloride,  $\text{oleyl-N}(\text{CH}_3)(\text{C}_2\text{H}_4\text{OH})_2\text{Cl}$ ), commercial products of Akzo Chemical (now Akzo Nobel) which contained about 50% active cationic surfactant in a solvent of water and isopropyl alcohol. The counterion, the sodium salt of 2-hydroxy benzoate ( $\text{NaSal}$ ), was a product of MCB Manufacturing Chemicals, Inc. (GR purity grade). Surfactant concentrations were kept at 5 mM, while counterion concentrations varied from 3 mM to 12.5 mM, so that the molar ratio of counterion to surfactant,  $\xi$ , varied from 0.6 to 2.5.

### Rheology measurements

#### a) Shear viscosity and first normal stress difference measurements

First normal stress differences,  $N_1$ , and shear viscosity were measured at  $22 \pm 2^\circ\text{C}$  (room temperature) using a Rheometrics RMS 800 rheometer. The normal force and shear stress on the upper fixed cone (50 mm in diameter and 0.04 radians in cone angle) were measured. Due to the limited sensitivity of the transducers, the lowest shear rate tested was  $25 \text{ s}^{-1}$ . Also no measurements could be made at shear rates above  $800 \text{ s}^{-1}$ , because of foaming of the surfactant solutions.

Inertial effects are very significant for  $N_1$  values less than 1000 Pa in the range of shear rates of interest. Thus, all first normal stress difference results were corrected for inertial effects using the following equation given by Macosko (1994):

$$N_{1\text{corrected}} = N_{1\text{reading}} + 0.15\rho\Omega^2 R^2 \quad (19)$$

where  $\rho$  is solution density,  $\Omega$  is angular velocity and  $R$  is cone radius. Because the inertial force is in the opposite direction to the normal force, the correction term,  $0.15\rho\Omega^2 R^2$ , is added to the rheometer output, giving an increase in  $N_{1\text{corrected}}$ .

#### b) Dynamic viscoelasticity measurements

Because of its greater sensitivity to low torque measurements, dynamic viscoelasticity measurements were car-

ried out with a Rheometrics RFSII rheometer, which is equipped with transducers much more sensitive than those on the RMS 800 instrument. A Couette cell was used with a cup diameter of 34 mm and bob diameter of 32 mm, giving a gap of 1 mm. The bob length was 32 mm. Temperature was controlled by a fluid bath to  $\pm 0.5^\circ\text{C}$  of the desired temperature.

### c) Extensional viscosity measurements

Extensional viscosity was measured using a Rheometrics RFX instrument, which employs two opposing nozzles to generate an extensional flow. Detailed analysis and description of the instrument can be found elsewhere (e.g. Walker et al., 1996). Nozzles with jet diameters of 1 mm and 2 mm were used to cover extension rates from  $5\text{ s}^{-1}$  to  $2000\text{ s}^{-1}$ . The separation gap between the two jets was set to be equal to the nozzle diameter. Samples were kept in a 250 ml jacketed beaker to allow temperature control by a circulation temperature controller within  $\pm 0.5^\circ\text{C}$  of the desired temperature. Solutions were sucked into the nozzle by a syringe pump to generate extensional flow between the two nozzles. Experiments were repeated three times, and the average reported.

### Drag reduction measurements

Drag reduction experiments were carried out in a recirculation system containing a 122 cm long, 0.617 cm diameter, stainless steel test-section. The system was temperature controlled to allow experiments to be run from  $2^\circ$  to  $150^\circ\text{C}$ . Entrance and exit corrections were applied and the system was calibrated with water. The accuracy of drag reduction measurements in this unit was more than adequate for comparing the relative effectiveness of drag reducing solutions.

### Cryo-TEM

Surfactant solution specimens were prepared for transmission electron microscopy at cryogenic temperature (cryo-TEM) in a controlled temperature and humidity chamber, by applying a small drop of the studied solution onto a perforated carbon film supported on an electron microscope grid, blotting it to form a thin ( $\sim 0.2\text{ }\mu\text{m}$ ) liquid film, and rapidly plunging the grid into liquid ethane at its freezing point, thus vitrifying the liquid film (Talmon, 1996). By avoiding water crystallization, the microstructure is not disturbed, and the images obtained reflect the true microstructures in the original solutions. However one should bear in mind that blotting to form the thin film subjects the solution to very

high flow rates. Images of the vitrified samples were recorded with either a Philips CM12 or a JEOL 2000 FX transmission electron microscope operated at 100 kV, using Gatan cooling holders at about  $-170^\circ\text{C}$ . Low-dose images were taken at  $4\text{ }\mu\text{m}$  nominal underfocus.

## Results and discussion

### Swirl decay time (SDT)

Viscoelasticity could be simply characterized by the swirl decay time (SDT), proposed and used by Nash (1965a,b). He set up a swirling motion in a fixed volume of solution in a flask and noted the time between the stopping of the vessel rotation and the cessation of the solution movement before recoil, which he defined as SDT. The shorter the SDT, the higher the viscoelasticity of the solution.

As a simple characterization method, the SDTs of surfactant systems under investigations were measured (Table 1). A 100 ml beaker was filled with 60 ml of surfactant solution, and then the solution was placed on a magnetic mixer with a 1-inch stirring bar. The rotational speed of the mixer was set to a fixed value. SDT was measured as the difference between the time at which the mixer was stopped and the time when the solution started to recoil.

All solutions showed recoil when the motion was stopped, which means that all solutions were viscoelastic. The data in Table 1 show that when the counterion/surfactant ratio,  $\xi$ , was 0.6, SDT was significantly longer than those for other ratios. Thus, the solutions at  $\xi = 0.6$  are less viscoelastic than the others. There were no significant differences in SDT among the solutions with  $\xi \geq 1$ .

### First normal stress differences

For first normal stress difference,  $N_1$ , and viscosity measurements, the step rate method was used, i.e., a fixed steady shear rate was applied to the sample at zero time and held long enough until steady state was reached. Data were recorded continuously. Then the motor was turned off to allow the sample to relax to zero  $N_1$  or zero shear stress. The sample was allowed

Table 1 Swirl decay time (seconds)

Concentrations (mM/mM)	5/3	5/5	5/9.5	5/12.5
Arquard 16-50/NaSal	2.8	1.7	-	1.6
Ethoquad O/12/NaSal	2.6	1.7	1.7	1.7



Fig. 1a First normal stress difference ( $N_1$ ) for Arquad 16-50 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$

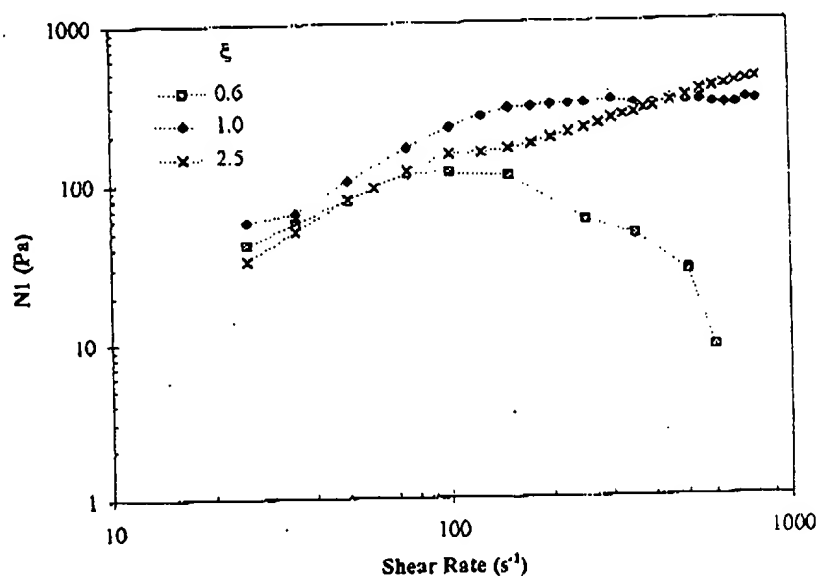
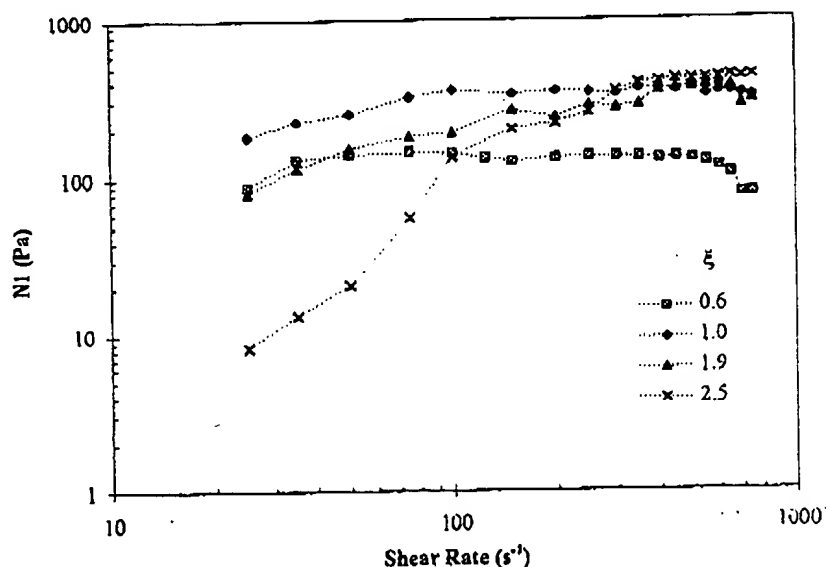


Fig. 1b First normal stress difference ( $N_1$ ) for Ethoquad O/12 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$



to rest for at least 300 s before the next measurement to eliminate any possible "memory effect" of the viscoelastic solution. This effect may affect the results if the rate sweep test method is used, in which the shear rate is ramped up so the sample has no time to relax. In that procedure, the data at each shear rate depend on both current and shear history. Shorter rest times may give memory effects as noted by Hu and Matthys (1997). For their surfactant system, a 300-s rest time was adequate to eliminate memory effects.

Figures 1a and 1b show normal stress difference results for 5 mM Arquad 16-50/NaSal and 5 mM Ethoquad O/12/NaSal solutions at various counterion-sur-

factant ratios. At  $\xi = 0.6$ ,  $N_1$  values for both systems increase at low shear rates to a low level and then decrease with increase in shear rate. For the  $\xi = 0.6$  Arquad 16-50/NaSal system,  $N_1$  vanishes at high shear rates. When  $\xi$  increases to 1,  $N_1$  values of both systems increase with shear rate at low shear rates ( $< 100 \text{ s}^{-1}$ ) and reach a plateau at high shear rates. The plateau  $N_1$  values are significantly higher than those for  $\xi = 0.6$ . This is consistent with the SDT results presented above. The Ethoquad O/12/NaSal system has a somewhat higher plateau level for  $N_1$  than the Arquad 16-50/NaSal system. For both surfactant systems, if  $\xi$  further increases to 2.5,  $N_1$  increases with shear rate up to the

Fig. 2a Stress development in the start-up of steady state shear flow at shear rate of  $100 \text{ s}^{-1}$  for the Arquad 16-50 (5 mM)/NaSal (3 mM) system

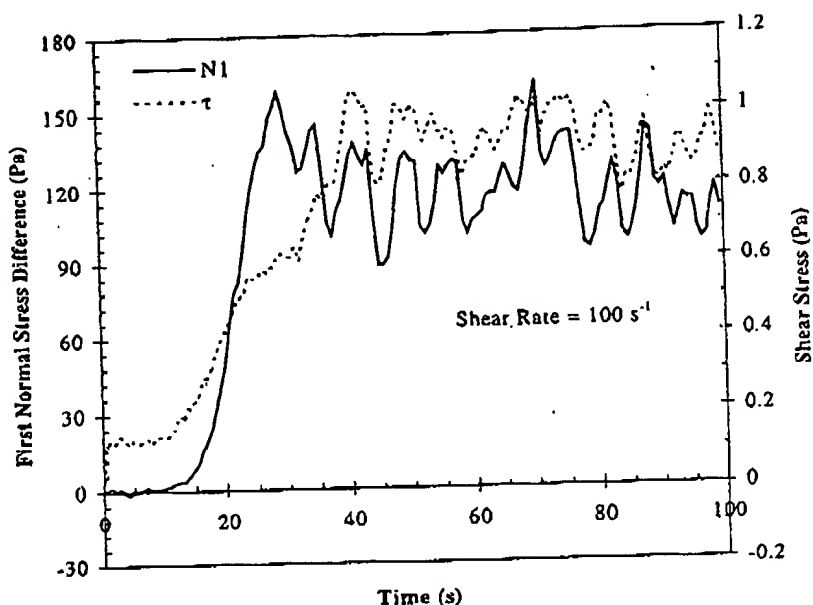
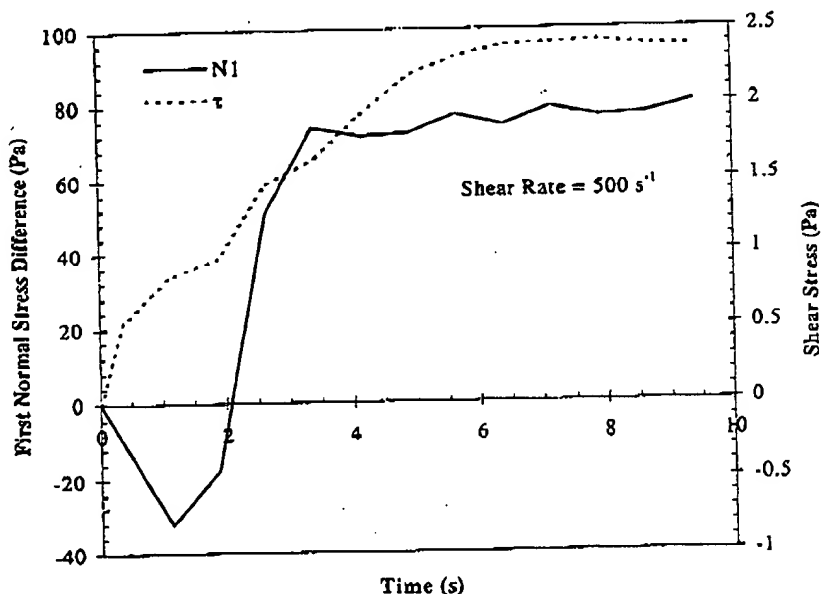


Fig. 2b Stress development in the start-up of steady state shear flow at shear rate of  $500 \text{ s}^{-1}$  for the Arquad 16-50 (5 mM)/NaSal (3 mM) system



highest shear rate tested ( $800 \text{ s}^{-1}$ ) and there is no plateau. It is interesting to note that at low shear rates,  $N_1$  values at  $\xi = 2.5$  are smaller than those at  $\xi = 1$ , while at high shear rates, the former are larger than the latter. That is, the  $N_1$ -shear rate curve actually shifts to the right (lower  $N_1$  at low shear rates) when the ratio increases. This trend was confirmed by an additional test on the Ethoquad O/12/NaSal system at  $\xi = 1.9$ . The  $\xi = 1.9$  curve lies between the  $\xi = 1$  and the  $\xi = 2.5$  curves (Fig. 1b).

The first normal stress difference data show that both the Arquad 16-50 and Ethoquad O/12 systems are

viscoelastic, though the magnitudes of the  $N_1$  values vary with counterion/surfactant ratio. The viscoelasticity is associated with micellar networks, as shown in the cryo-TEM pictures which we discuss in a later section.

#### Start-up stress development

Figures 2a and 2b show the transient response of shear and normal stress in the start-up of steady state shear flows at  $100 \text{ s}^{-1}$  and  $500 \text{ s}^{-1}$  for the Arquad 16-50 (5 mM)/NaSal (3 mM) ( $\xi = 0.6$ ) system. At  $100 \text{ s}^{-1}$

Fig. 3a Stress development in the start-up of steady state shear flow at shear rate of  $100 \text{ s}^{-1}$  for the Arquad 16-50 (5 mM)/NaSal (5 mM) system

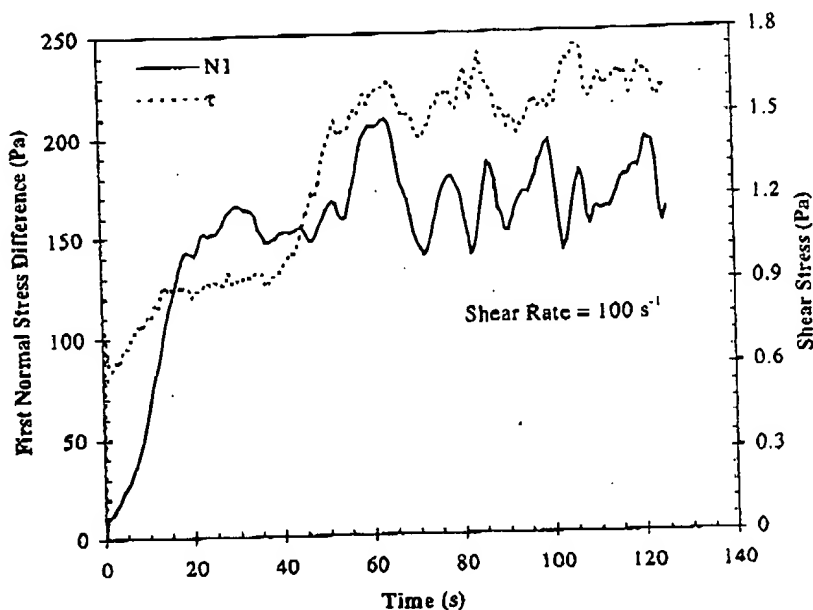
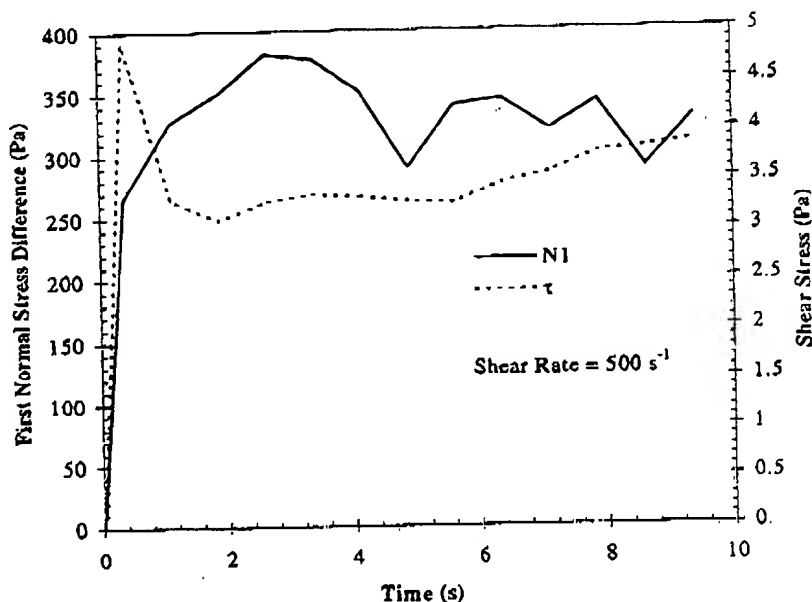


Fig. 3b Stress development in the start-up of steady state shear flow at shear rate of  $500 \text{ s}^{-1}$  for the Arquad 16-50 (5 mM)/NaSal (5 mM) system



(Fig. 2a), both shear stress and normal stress assume constant small values for over 10 s after the shear starts and then increase to higher plateau values. At  $500 \text{ s}^{-1}$  (Fig. 2b), however, the initial period is not observed; both stresses increase gradually to the plateau. The normal stress shows some negative values immediately after start-up, which are believed to be due to error in transducer readings at low values.

For the Arquad 16-50 (5 mM)/NaSal (5 mM) ( $\xi = 1.0$ ) system at  $100 \text{ s}^{-1}$  (Fig. 3a), the stresses increased to an initial plateau without going through an induction period, unlike in the  $\xi = 0.6$  case. After an

initial plateau lasting over 20 s, both stresses increase further to their final plateaus. At higher shear rate,  $500 \text{ s}^{-1}$  (Fig. 3b), however, both the induction period and the initial plateau are eliminated. The normal stress showed modest overshoot and then reached the final plateau region, while the shear stress showed a large overshoot first, then it dropped, and finally increased to the plateau.

Contrary to the above, the Arquad 16-50 (5 mM)/NaSal (12.5 mM) ( $\xi = 2.5$ ) system (Figs. 4a and 4b), differs from the two systems with lower ratios. At both shear rates,  $100 \text{ s}^{-1}$  and  $500 \text{ s}^{-1}$ , both shear stress and

Fig. 4a Stress development in the start-up of steady state shear flow at shear rate of  $100 \text{ s}^{-1}$  for the Arquad 16-50 (5 mM)/NaSal (12.5 mM) system

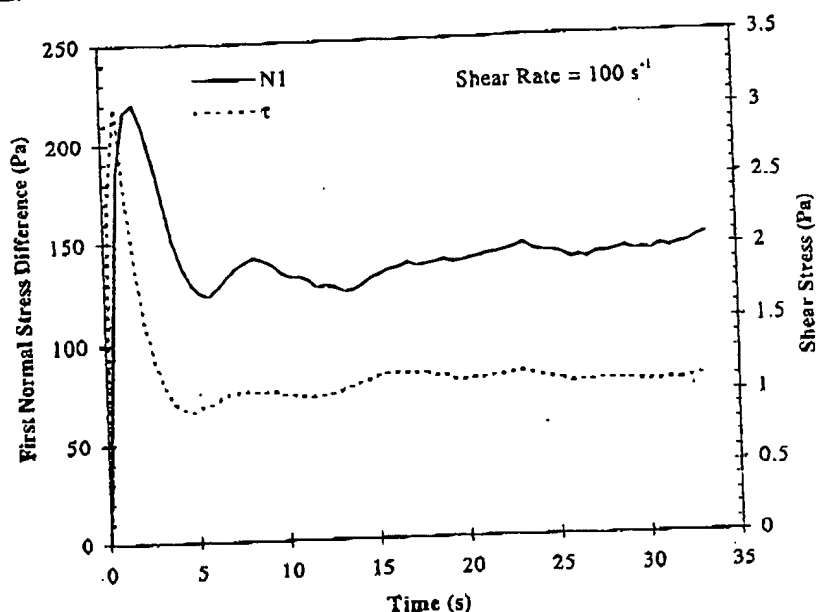
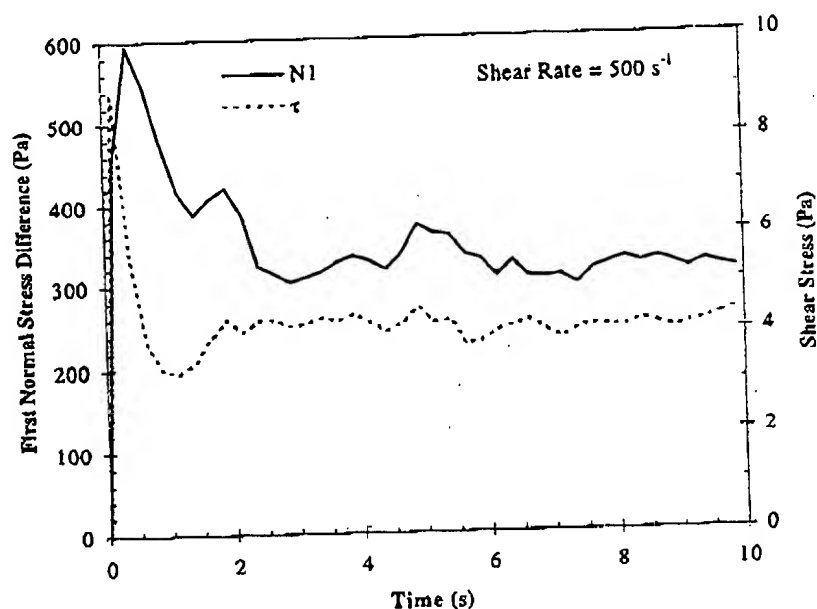


Fig. 4b Stress development in the start-up of steady state shear flow at shear rate of  $500 \text{ s}^{-1}$  for the Arquad 16-50 (5 mM)/NaSal (12.5 mM) system



normal stress showed a large overshoot and then rapid decrease to a final plateau. The peak value of shear stress overshoot is about three times the plateau value, while normal stress overshoot is of lesser extent but still nearly twice the plateau value.

The data in Figs. 2a–4b show that stress development is strongly counterion ratio dependent. For  $\xi = 0.6$ , there is insufficient counterion to neutralize all the positive charges on the surfactant headgroups, and thus either a very weak or no micellar network exists in the solution. Thus, it is not surprising that no overshoot is observed when shear is applied, because the over-

shoot is caused by the over-reaction of the network structure to shear. On the contrary, when  $\xi = 2.5$ , a strong surfactant network is formed in the solution and, as expected, significant overshoot is observed.  $\xi = 1.0$ , however, is a critical ratio. Both shear and normal stresses show overshoot at high shear rate but not at low shear rate, though the normal stress overshoot at high shear rate is small. At low ratio ( $\xi = 0.6$  and  $1.0$ ) and low shear rates, the stresses develop in two steps, i.e., stresses go through either an induction period or an initial plateau. At high shear rates, however, all stresses, even at low ratio, reach a plateau in a single step, in

Fig. 5a Viscosity vs. shear rate for Arquat 16-50 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$

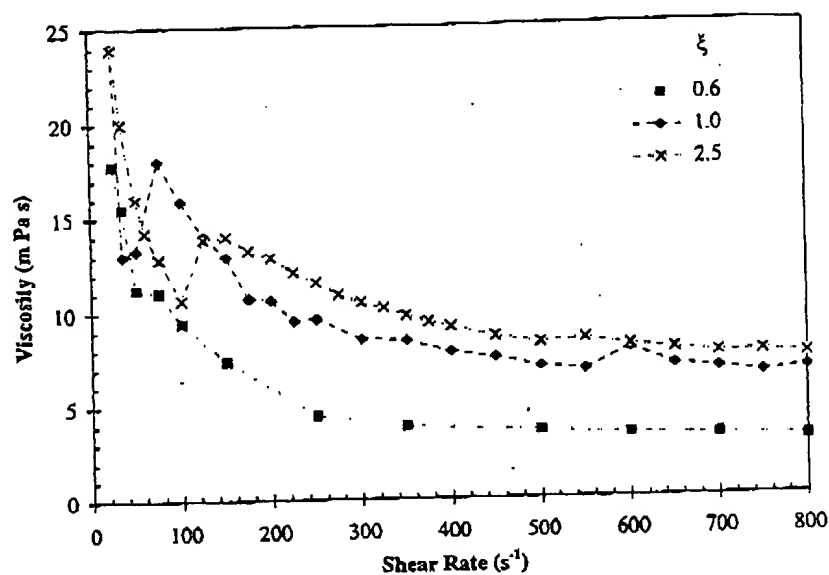
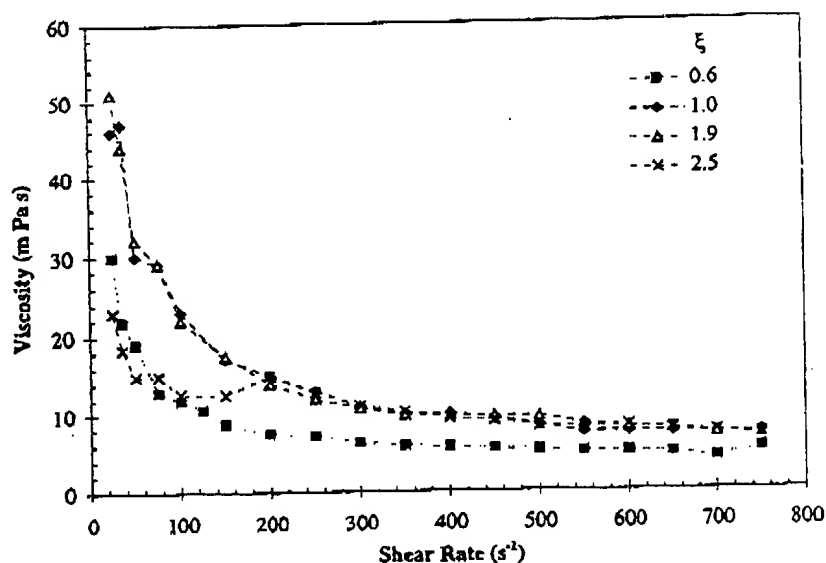


Fig. 5b Viscosity vs. shear rate for Ethoquad O/12 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$



some cases following an overshoot. Thus, increase in the shear rate has a similar effect on micellar network formation to the effect of increase in the amount of counterion. The trend in stress start-up observed here agrees with that reported by Hu and Matthys (1996) for similar surfactant concentrations. Smaller overshoot of normal stress compared to shear stress was also observed by Rehage and Hoffmann (1988) in a 100 mM CPyCl (cetylpyridinium chloride)/60 mM NaSal system at a shear rate of  $1 s^{-1}$ . They observed no overshoot at the very low shear rate of  $0.05 s^{-1}$ .

The lower peak values of both shear and normal stresses at  $100 s^{-1}$  and their trend, i.e., small or no overshoot at lower shear rate, are consistent with the results

of Rehage and Hoffmann (1988) as mentioned above. Apparently, this shear rate is insufficient to fully extend the micellar network and release energy stored in the network. Other data showing large overshoots at  $150 s^{-1}$  and above (Lu, 1997b) indicate that the shear forces above  $150 s^{-1}$  are sufficient to fully extend the micellar structure, causing some form of structural rearrangement.  $N_1$  and shear stress data at longer times are described later.

#### Shear viscosity and shear induced structure

Figures 5a and 5b show the effect of shear rate on the shear viscosities of the Arquat 16-50 (5 mM)/NaSal

Fig. 6a First normal stress difference and shear stress vs. time for Ethoquad O/12 (5 mM)/NaSal (12.5 mM) solution at  $150 \text{ s}^{-1}$ . Shear stopped at 100 s

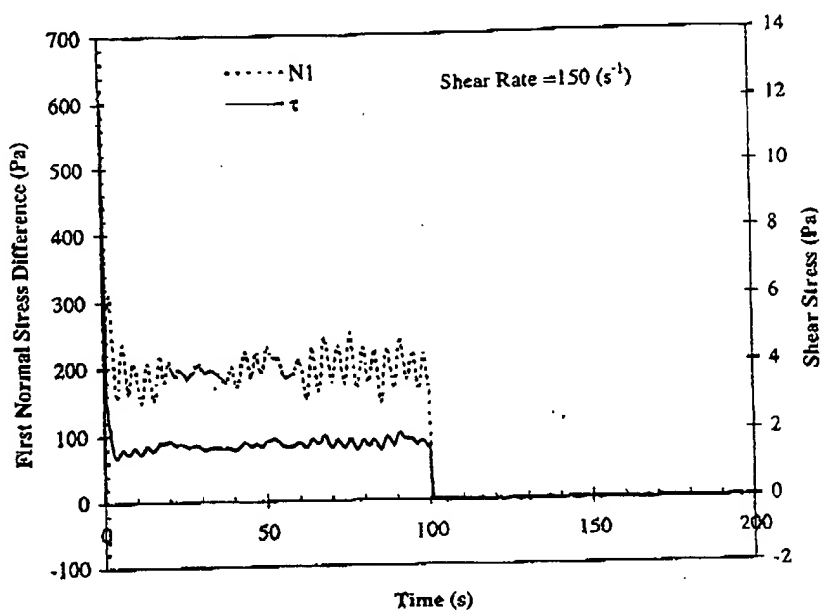
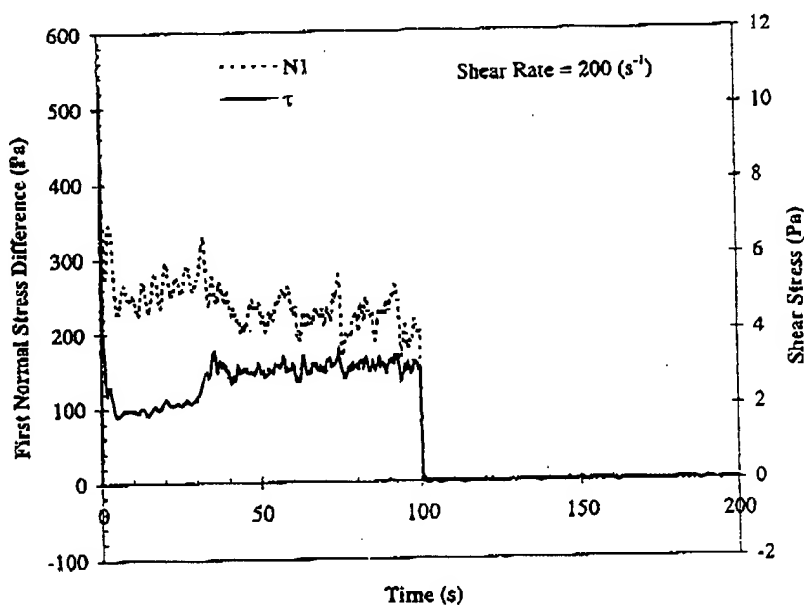


Fig. 6b First normal stress difference and shear stress vs. time for Ethoquad O/12 (5 mM)/NaSal (12.5 mM) solution at  $200 \text{ s}^{-1}$ . Shear stopped at 100 s



and the Ethoquad O/12 (5 mM)/NaSal systems, respectively. With some notable exceptions, all systems are shear thinning at shear rates above  $25 \text{ s}^{-1}$ . One exception is the Arquad 16-50 (5 mM)/NaSal (5 mM) system. Viscosity increases abruptly above a shear rate of  $35 \text{ s}^{-1}$ , reaching a maximum at about  $75 \text{ s}^{-1}$ . The Arquad 16-50 (5 mM)/NaSal (12.5 mM) system has a similar increase in viscosity at shear rates above  $100 \text{ s}^{-1}$ , reaching a maximum at about  $150 \text{ s}^{-1}$ . For the Ethoquad O/12/NaSal system, an increase in viscosity is observed for the  $\xi = 2.5$  system above  $150 \text{ s}^{-1}$  with a peak at about  $200 \text{ s}^{-1}$ . At high shear rates these three

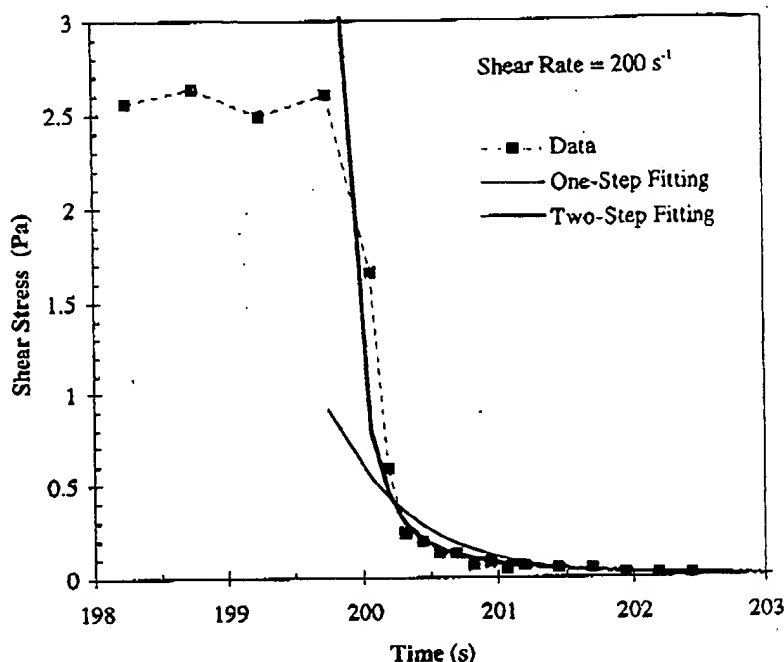
systems are shear thinning after the sudden viscosity increase. It is also quite possible that solutions of both surfactants at lower  $\xi$ , which do not show viscosity increases at shear rates above  $25 \text{ s}^{-1}$ , may show viscosity increase at shear rates below those we could measure ( $25 \text{ s}^{-1}$ ).

Abrupt increases in viscosity for surfactant systems were taken as evidence of the existence of shear-induced-structures (SIS) by some researchers (Ohlendorf et al., 1986a,b; Rehage et al., 1986; Bewersdorff and Ohlendorf, 1988; Bewersdorff, 1989, 1996). These researchers observed that the viscosity was usually very

Fig. 7 Shear stress vs. time for Arquad 16-50 (5 mM)/NaSal (12.5 mM) system. Shear stopped at 200 s. The two-step fitting is done by a double exponential function:

$T = T_1 e^{-\frac{t-t_0}{\tau_1}} + T_2 e^{-\frac{t-t_0}{\tau_2}}$  and the one-step fitting is done by a single exponential function:

$$T = T_0 e^{-\frac{t-t_0}{\tau}}$$



low at low shear rates and then at a critical shear rate, viscosity suddenly increased to high values; in some cases the increase was 2.5 times. The term "jump" was used to describe this sudden increase. In their data, the viscosity before the jump was never higher than the peak viscosity immediately after the jump. Their viscosity jumps depended on concentration, temperature and shear rate. The critical shear rate where the jump occurred increased with surfactant concentration and with temperature, and the jump was only observed at low temperature. The solutions were always shear thinning after the jump. The above authors suggested that the increase in viscosity was induced by an abrupt change in the microstructure of the surfactant solutions.

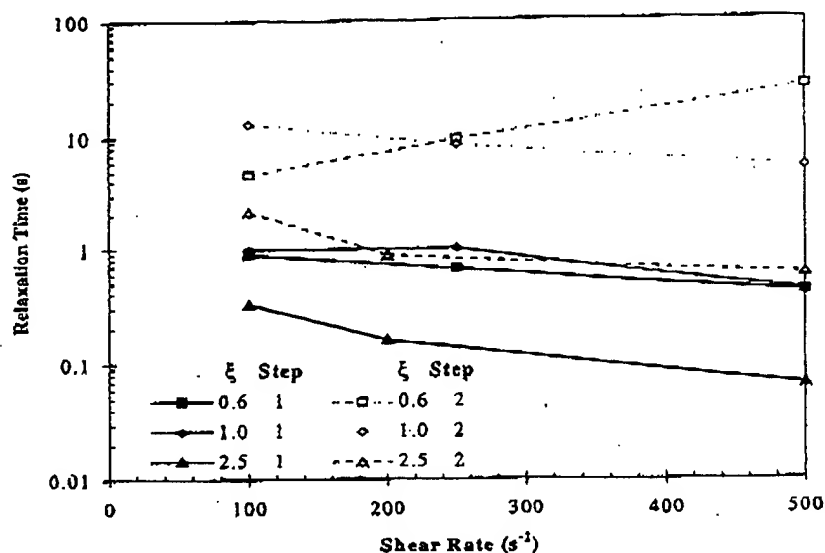
Hoffmann and Rehage (1987) classified viscoelastic surfactant systems into two types. In the first and more general type, the structures causing viscoelastic behavior are present in the stagnant solution. In the second type viscoelasticity is observed only after a certain threshold shear rate is exceeded. Systems of the second type were called shear-induced viscoelastic systems (Hoffmann and Rehage, 1987). This implies that for low surfactant concentrations and with low counterion-to-surfactant ratios (solutions of the second type), the network structure is weak or incomplete. Shear is needed to induce the formation of a network and viscoelasticity. For surfactant systems with high surfactant concentrations and high counterion to surfactant ratio, a network exists in the solutions and no shear should be needed to promote viscoelasticity.

The data in Figs. 5a and 5b appear to contradict their hypothesis since sudden viscosity increases happen

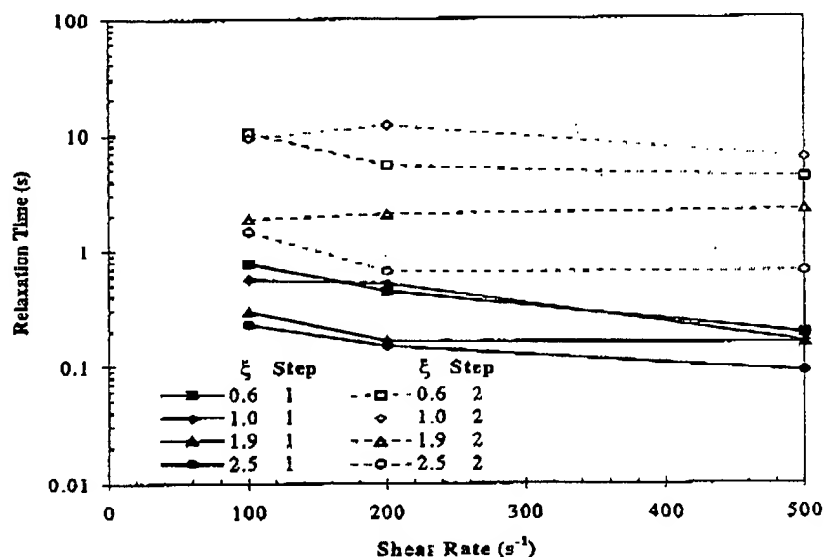
at high counterion-surfactant ratio, where shear should not be needed to induce the network formation. It should be pointed out, however, that the abrupt viscosity increases observed here differ from the viscosity "jumps" above the initial plateau viscosities observed for SIS by those authors. In our case, the increase in viscosity never doubles its value and the initial viscosities at low shear rates are greater than the peak after the viscosity increase. Thus, these sudden increases in viscosity are apparently caused by network structure rearrangement under shear, which may also be linked with micellar growth under shear. Lu et al. (1998) described a different effect of shear on a network microstructure for a particular surfactant composition at a particular temperature.

Large overshoots for the Ethoquad O/12 (5 mM)/NaSal (12.5 mM) system were observed at 150 s<sup>-1</sup> and above (Lu, 1997b). For that same system, we observed an abrupt viscosity increase around 200 s<sup>-1</sup> (Fig. 5b). It is not obvious whether that change is a shear effect or a time effect. If it is a shear effect, then immediately after the application of shear at a critical shear rate, the solution should assume the higher viscosity. If it is a time effect, the new high viscosity is attained after a certain length of time of shear. Thus, we examined the stress development over a longer time period for both shear stress and normal stress at shear rates around 200 s<sup>-1</sup>. Figures 6a and 6b show these data at 150 s<sup>-1</sup> and 200 s<sup>-1</sup> shear rates, respectively. Overshoot for both shear stress and  $N_1$  is observed at the far left. At 150 s<sup>-1</sup>, steady average levels were reached in less than 5 s after overshoot for both shear stress and normal stress but with

**Fig. 8a** Shear stress relaxation times for Arquad 16-50 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$ . The relaxation is a two-step process. The two relaxation time constants,  $\tau_1$  and  $\tau_2$ , are obtained by fitting shear stress data by:

$$T = T_1 e^{-\frac{t-\tau_0}{\tau_1}} + T_2 e^{-\frac{t-\tau_0}{\tau_2}}$$


**Fig. 8b** Shear stress relaxation times for Ethoquad O/12 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$ . The relaxation is a two-step process. The two relaxation time constants  $\tau_1$  and  $\tau_2$ , are obtained by fitting shear stress data by:

$$T = T_1 e^{-\frac{t-\tau_0}{\tau_1}} + T_2 e^{-\frac{t-\tau_0}{\tau_2}}$$


some oscillations in  $N_1$ . When the shear rate was increased to  $200 \text{ s}^{-1}$  and also to  $250 \text{ s}^{-1}$ , the shear stress quickly reached an initial steady level after overshoot. However, after about 30 s for the  $200 \text{ s}^{-1}$  shear rate (Fig. 6b) and 15 s for  $250 \text{ s}^{-1}$  (Lu, 1997b), shear stress increased again to a higher steady level. This latter steady level was reported in Fig. 5b as the viscosity at that shear rate. Figure 6b shows that the abrupt viscosity increase occurring around  $200 \text{ s}^{-1}$  for this system (Fig. 5b) was actually built-up during the shearing process, possibly due to network rearrangement and/or to micellar growth under shear. Thus, if this increase is shear-thickening, then it is really a time-dependent thickening process. Accompanying the step increase in

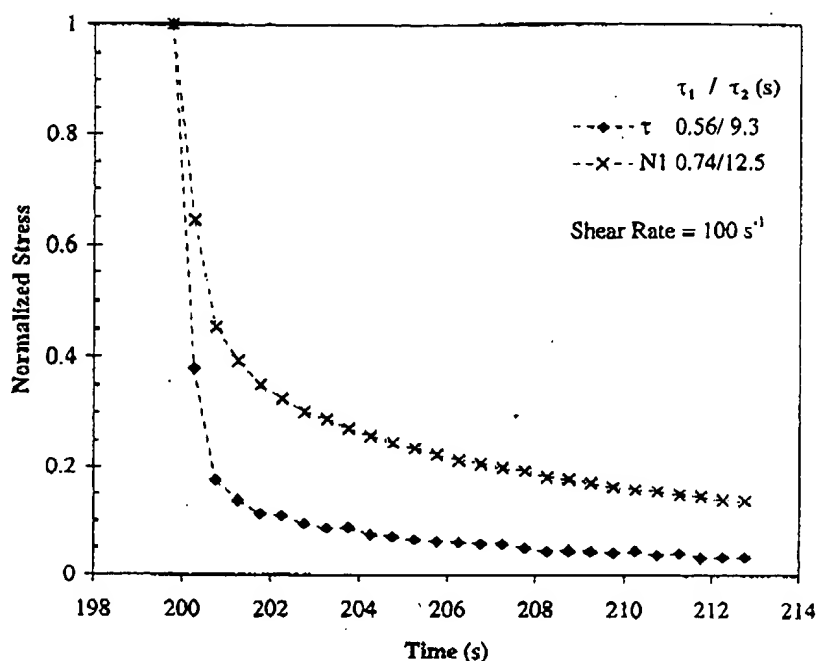
shear stress,  $N_1$  values showed a small decrease at  $200 \text{ s}^{-1}$  (Fig. 6b) and  $250 \text{ s}^{-1}$  (Lu, 1997b). Thus, surprisingly, whatever change in the microstructure caused the viscosity increase had a smaller, negative effect on  $N_1$ .

#### Stress relaxation

Shear and normal stress data for all systems were examined for relaxation behavior. As found earlier in flow birefringence measurements (Lu and Zakin, 1995; Lu, 1997b), the relaxation for both  $N_1$  and shear stress is a two-step process, i.e., a quick drop followed by a slow



Fig. 9 Normalized shear stress and first normal stress difference vs. time for the Ethoquad O/12 (5 mM)/NaSal (5 mM) system. Shear stopped at 200 s. Both stresses are normalized by their respective plateau values. The two-step relaxation time constants are shown for both stresses.  $N_1$  takes longer to relax than shear stress



decay. This was also reported by Shikata et al. (1988b) for 100 mM CTAB/NaSal solutions at various NaSal concentrations for shear rates higher than a critical value, and by Hu and Matthys (1995) for another cationic surfactant solution at  $\xi = 1.0$ . However, Hu and Matthys (1996) claimed that the stress relaxation is a one-step process at high counterion to surfactant ratio. Our data show that even at a counterion-to-surfactant ratio,  $\xi = 2.5$ , both for a system previously studied (Lu et al. 1997a,b) and all systems studied here, after the shear stopped, the stress always showed a rapid drop and then a slow relaxation process. Thus, the relaxation must be a two-step process which can be fit with a double exponential function as used by several authors (Shikata et al., 1988b; Hu and Matthys, 1995; Lu et al., 1997a,b):

$$T = T_1 e^{-\frac{t-t_0}{\tau_1}} + T_2 e^{-\frac{t-t_0}{\tau_2}} \quad (2)$$

where  $T$ ,  $T_1$  and  $T_2$  are shear stress or normal stress,  $t_0$  is the time when shear stopped,  $\tau_1$  and  $\tau_2$  are time constants for the first (fast) and second (slow) step, respectively. The details for fitting can be found in Matsuoka (1968).

Figure 7 shows stress relaxation for the Arquad 16-50 (5 mM)/NaSal (12.5 mM) system. The two-step fitting clearly fits the data much better than the one-step fitting. One-step fitting obviously cannot represent the initial quick drop after the shear stopped. Shikata et al. (1988b) reported that the qualitative features of the relaxation were about the same for all the systems in their study over a range of  $\xi$  of 0.7 to 4.0. In their experi-

ments, the relaxation was a one-step process at low shear rates and a two-step process at shear rates higher than a critical value. Whether it was one-step or two-step was not ratio dependent.

Figures 8a and 8b show the two time constants for Arquad 16-50 (5 mM)/NaSal at three  $\xi$ 's and for Ethoquad O/12 (5 mM)/NaSal at four  $\xi$ 's. In addition to one obvious feature, i.e.,  $\tau_1 < \tau_2$ , all time constants, except one, decrease with increasing shear rate. The one exception is for the Arquad 16-50 (5 mM)/NaSal (3 mM) system, whose second-step relaxation time increases with shear rate. This increase was also observed by Shikata et al. (1988b) for the 100 mM CTAB/NaSal system at low NaSal concentration. When  $\xi$  increases from 0.6 to 1.0, relaxation times do not change much except for Arquad 16-50 (5 mM)/NaSal (3 mM) step 1. However, when  $\xi$  increases above 1.0, relaxation times for both steps significantly decrease. Shikata et al. (1988a) suggested that the relaxation time is affected by the free salicylate concentration and the free salicylate molecules behave like a catalyst for a disentangling reaction, so that with increasing NaSal concentrations, relaxation times decrease. Thus, increase in the ratio  $\xi$  over unity, has the same effect on relaxation time as increase in the shear rate. The trends of relaxation time change with shear rate agree with those reported by Shikata et al. (1988a,b) and by Hu and Matthys (1995).

Figure 9 compares the relaxation processes for shear stress and for normal stress for Ethoquad O/12 (5 mM)/NaSal (5 mM). The first normal stress difference,  $N_1$ , has longer time constants for both steps. This

Fig. 10a Drag reduction results for Arquad 16-50 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$ . ( $\xi = 2.5$  data from Chou (1991))

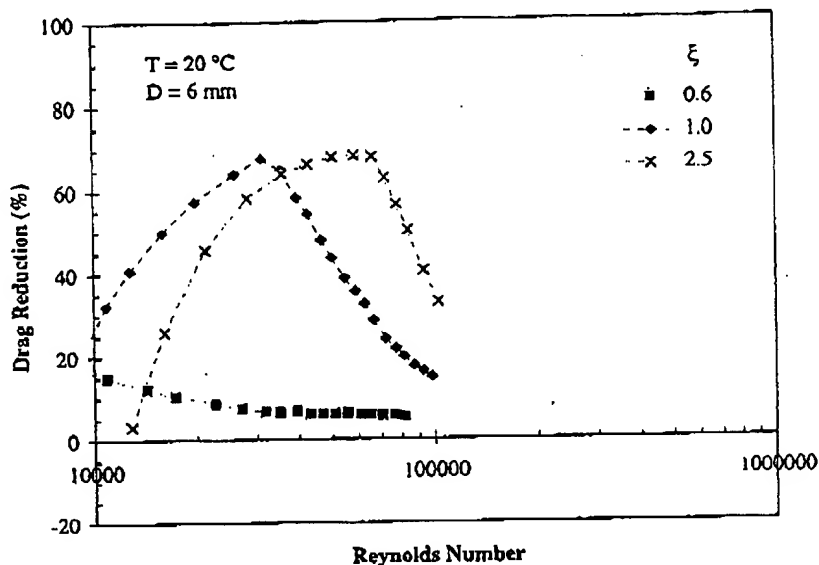
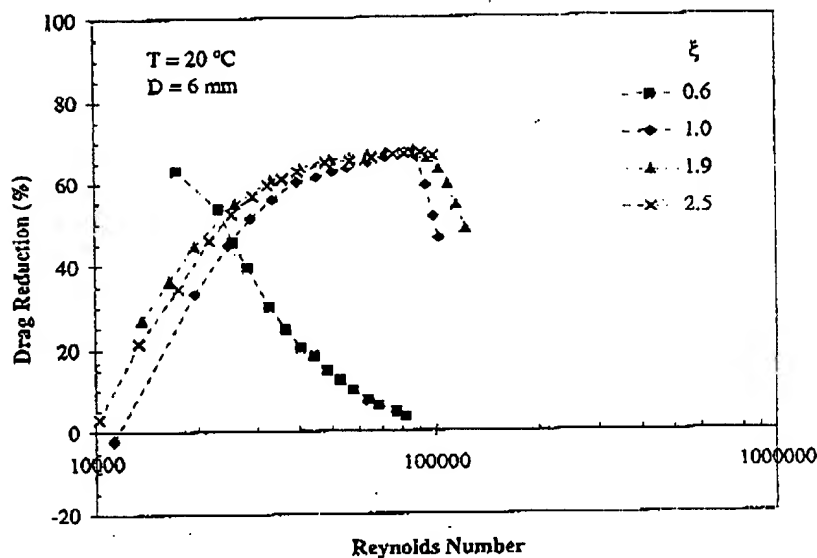


Fig. 10b Drag reduction results for Ethoquad O/12 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$ . ( $\xi = 1.9$  data from Chou (1991))



may be related to the rapid recoil of these viscoelastic surfactant solutions. Upon removal of shear, all surfactant solutions tested began to recoil in 1.6 to 2.8 s as indicated by the SDT results (see Table 1). The recoil motion was in the opposite direction to the shear flow, so the shear stress was reduced to zero more quickly.

#### Drag reduction

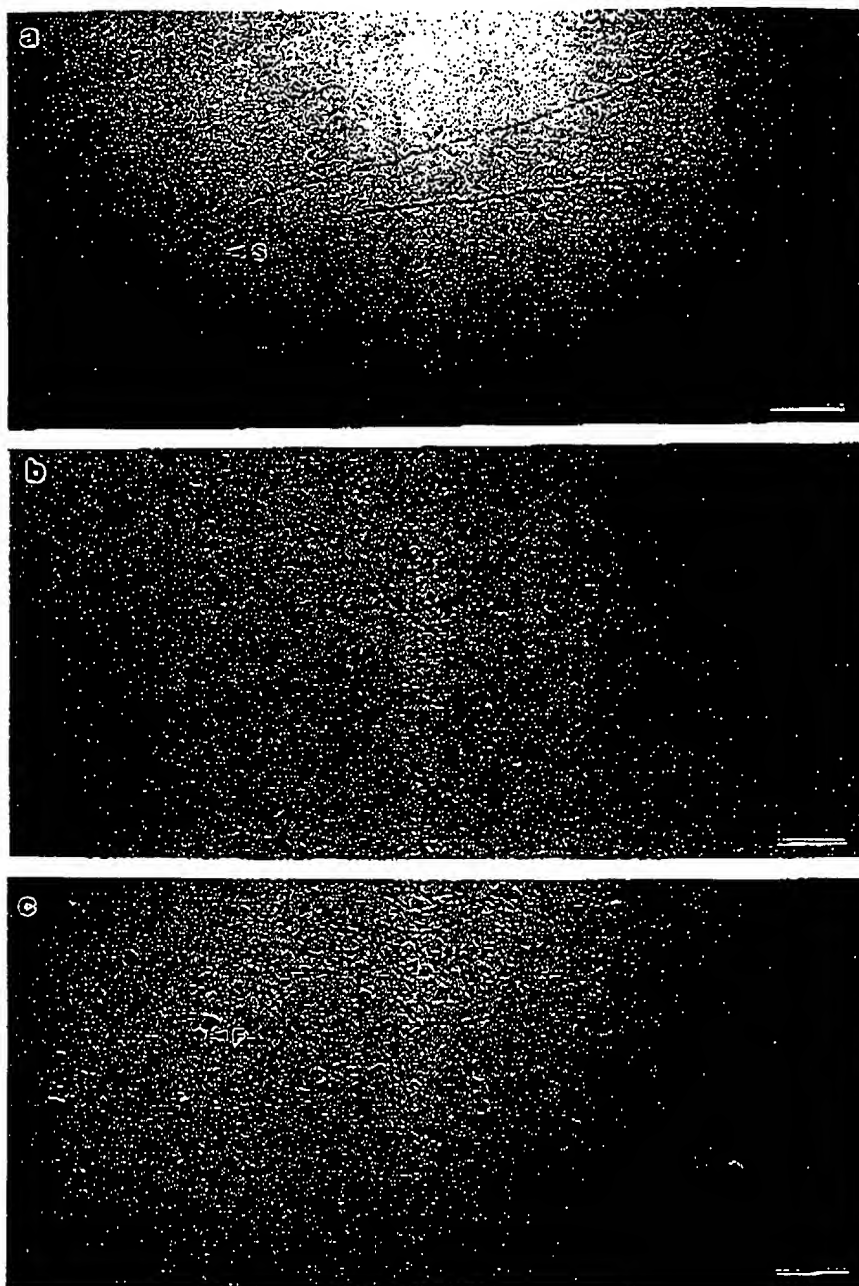
Drag reduction measurements on the same surfactant systems (Fig. 10a and 10b) show that both systems have at best modest drag reducing ability when  $\xi = 0.6$ . For the Arquad 16-50 (5 mM)/NaSal (Fig. 10a) system, when  $\xi = 0.6$ , there is close-to-zero

drag reduction. When  $\xi$  increases to 1, there is a large increase in drag reduction. With further increase in  $\xi$ , the drag reduction curve shifts to the right, i.e., drag reduction extends to higher Reynolds numbers. For the Ethoquad O/12/NaSal system (Fig. 10b), there is also a large increase in drag reduction when  $\xi$  increases from 0.6 to 1.0. With further increase in  $\xi$ , drag reduction extends to higher Reynolds numbers, but the differences among  $\xi = 1.0$ , 1.9 and 2.5 solutions are small.

#### Cryo-TEM images

Figures 11a,b,c and 12a,b,c show cryo-TEM images of the Arquad 16-50 (5 mM)/NaSal and the Ethoquad

Fig. 11 Cryo-TEM images of Arquad 16-50 (5 mM)/NaSal system.  $a=3$  mM NaSal,  $b=5$  mM NaSal and  $c=12.5$  mM NaSal; bars = 100 nm, S=spheres, F=frost



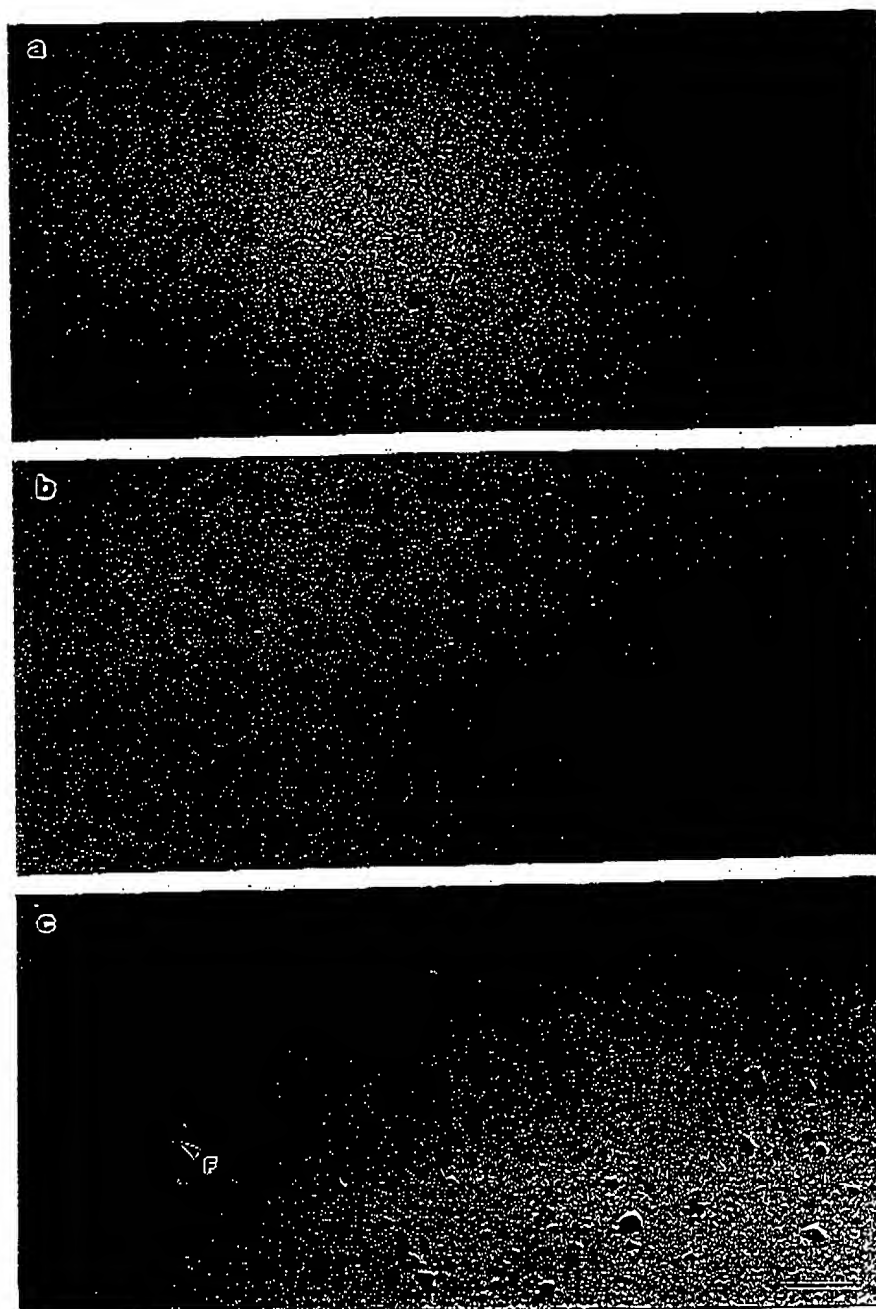
O/12 (5 mM)/NaSal systems at  $\xi = 0.6$ , 1.0 and 2.5, respectively.

For Arquad 16-50 (5 mM)/NaSal systems, when  $\xi = 0.6$ , several long thread-like micelles are observed and some spherical micelles are present. Those thread-like micelles do not form a network. When  $\xi$  reaches 1.0 and 2.5, thread-like micelles start to entangle or crosslink with each other and a micellar network is formed. The network at  $\xi = 2.5$  appears to be denser than that for  $\xi = 1.0$ . Thus, for this surfactant system,

with increasing counterion/surfactant ratio, the density of the micellar network increases from zero. For the Ethoquad O/12 (5 mM)/NaSal systems (Figs. 12a, b and c), however, the above trend can not be seen. A crosslinked micellar network is observed in the  $\xi = 0.6$  solution and with increasing  $\xi$ , no significant change in the network can be identified.

In addition to very long thread-like micelles and a network, there are many black dots in the images. The large dots are frost. Some of the small dots, particularly

Fig. 12 Cryo-TEM images of Arquad O/12 (5 mM)/NaSal system.  $a=3$  mM NaSal,  $b=5$  mM NaSal and  $c=12.5$  mM NaSal; bars = 100 nm, F = frost



in Figs. 11 a and 12 a, are spherical micelles. Others are the ends of thread-like micelles keeping in mind that these pictures are actually a 2-D projection of a 3-D network. These pictures confirm that there are network structures in these surfactant solutions even at low  $\xi$  for the Ethoquad O/12 system, even though shear was only applied for a short time in blotting the samples for cryo-TEM sample preparation. The cryo-TEM images cannot, unfortunately, be used to make quantitative statements about the microstructure and no significant

differences can be discerned among the  $\xi = 0.6$ , 1.0 and 2.5 samples for the Ethoquad O/12 system.

#### Dynamic viscoelastic measurements

Dynamic viscoelastic measurements were performed on Ethoquad O/12/NaSal solutions. Measurements on the solution at  $\xi = 0.6$  could not be made because of the low viscoelasticity of the solution and the limited sensi-

Fig. 13 Dynamic viscoelasticity measurement results for the Ethoquad O/12 (5 mM)/NaSal (12.5 mM) system.  $T=20^{\circ}\text{C}$

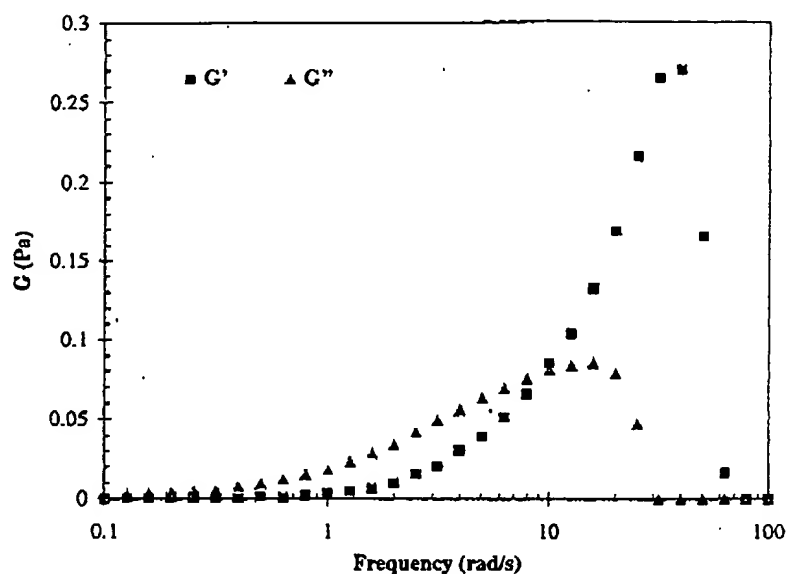
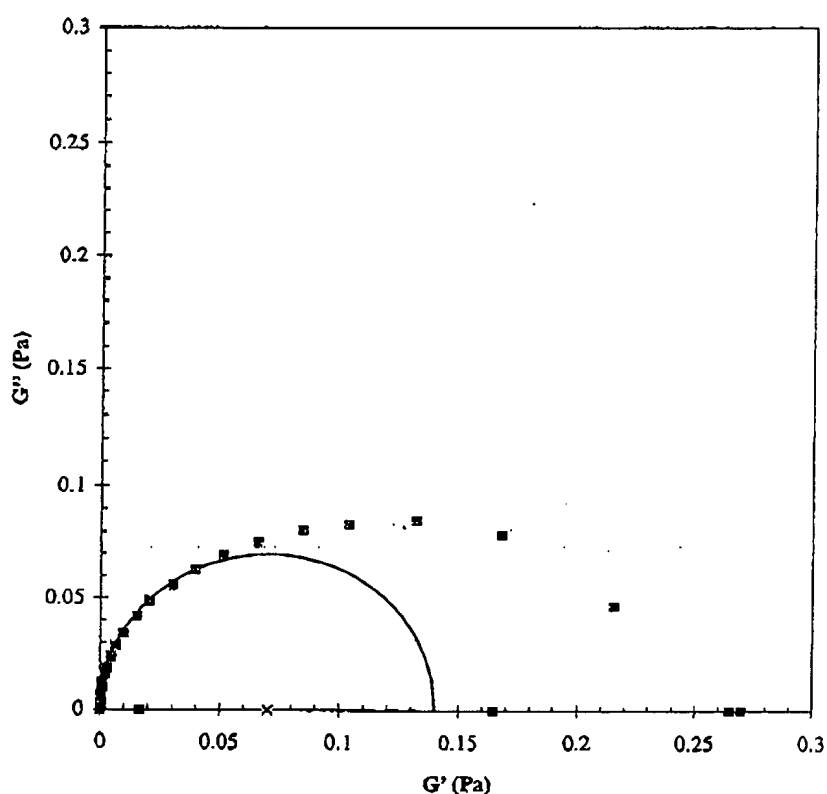


Fig. 14 Cole-Cole plot for Ethoquad O/12 (5 mM)/NaSal (12.5 mM) system.  $T=20^{\circ}\text{C}$



tivity of the transducer. Values of the elastic modulus,  $G'$ , and loss modulus,  $G''$ , for  $\xi = 1.0$  and  $\xi = 2.5$  were obtained and results for  $\xi = 2.5$  are shown in Fig. 13. Both  $G'$  and  $G''$  increased with frequency to a peak and then dropped down to zero. The  $G'$  curve crosses the  $G''$  curve at 10 rad/s, and  $G'$  values become

larger than  $G''$  values. This means the solution is viscoelastic as shown also by the larger  $N_1$  values. The  $\xi = 1.0$  system had the same trends in  $G'$  and  $G''$  but with lower  $G'$  and  $G''$  values than the  $\xi = 2.5$  system. A plateau for  $G'$  was not observed for either system. Other researchers observed that  $G'$  reached a plateau at

Fig. 15a Extensional viscosity of Arquad 16-50 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$

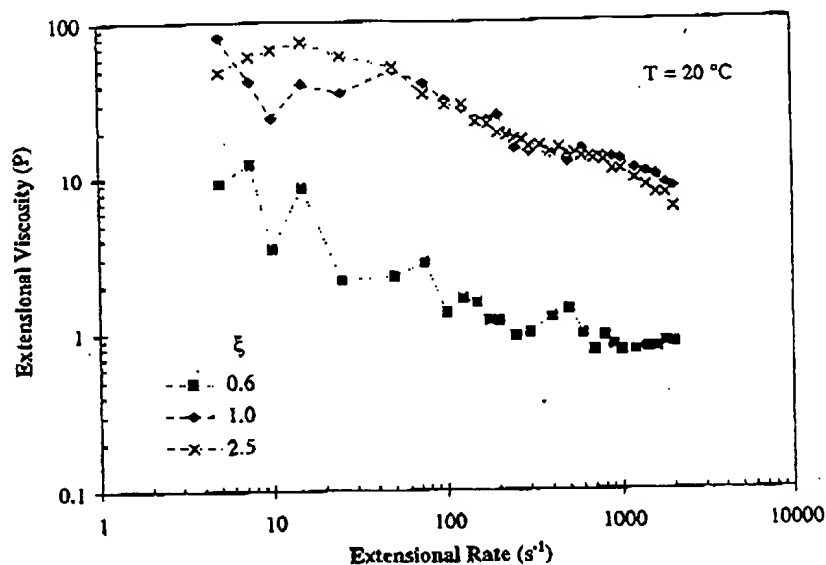
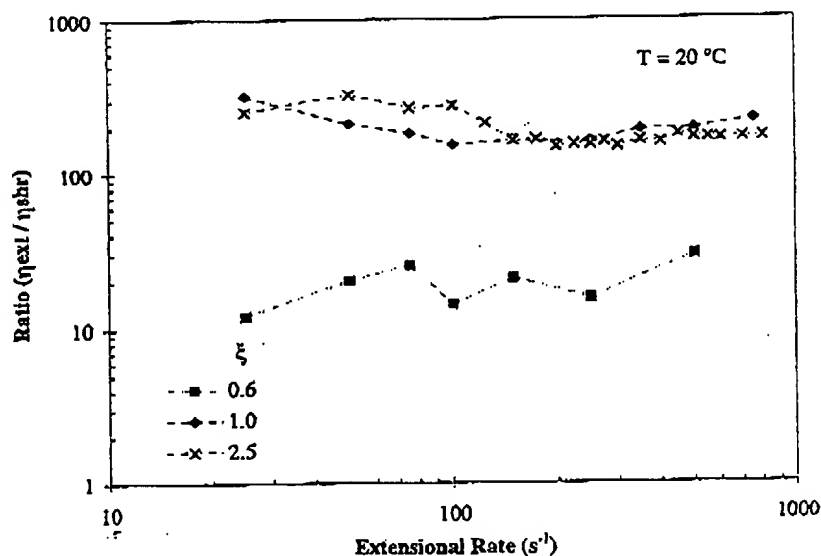


Fig. 15b Ratio of extensional viscosity to shear viscosity of Arquad 16-50 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$



high frequency with surfactant concentrations two orders of magnitude higher than ours (Shikata et al., 1987; Clausen et al., 1992). They concluded that this plateau indicated that under high angular frequencies the surfactant solutions behaved as elastic bodies and fully entangled networks existed. The lower concentration surfactant solutions studied here behaved differently with both  $G'$  and  $G''$  reaching a peak and dropping to zero. To check whether the zero values of  $G'$  and  $G''$  were caused by too high strain (0.5 rad) imposed on the system for it to stay in the linear viscoelasticity range at high frequency, a dynamic measurement at a fixed frequency of 100 rad/s with varying strain (strain sweep) was performed. The results (Lu,

1997b) showed that no linear viscoelasticity range existed at this frequency for this surfactant system, and both  $G'$  and  $G''$  reached zero even at strains lower than 0.02 rad. While zero  $G'$  values mean that the solution is non-viscoelastic at that frequency, it is not clear what zero values for both  $G'$  and  $G''$  mean. The frequency at which  $G'$  starts to drop to zero may correspond to the critical shear stress in drag reduction, above which the microstructure is destroyed and drag reduction is lost. A Cole-Cole plot was made for the  $G' - G''$  data of the  $\xi = 2.5$  Ethoquad O/12 system (Fig. 14). The data points do not fit a semicircle curve above a frequency of 3 rad/s (corresponding to a  $G'$  value of about 0.05 Pa), which means that these data are not well fit

Fig. 16a Extensional viscosity of Ethoquad O/12 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$

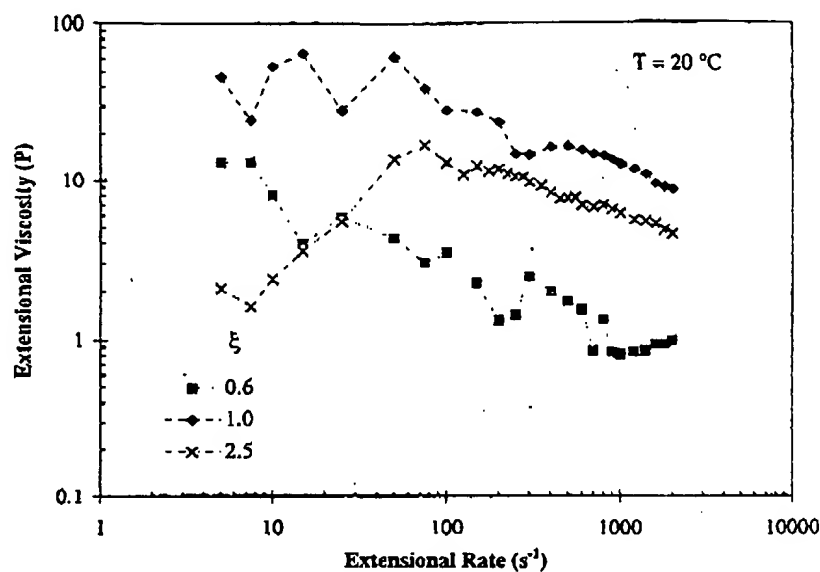
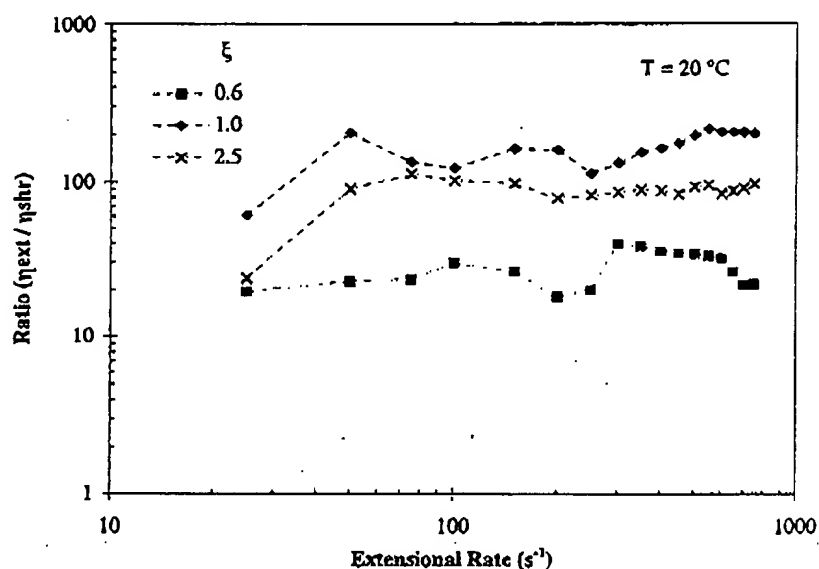


Fig. 16b Ratio of extensional viscosity to shear viscosity of Ethoquad O/12 (5 mM)/NaSal systems at different counterion/surfactant ratios,  $\xi$



by a simple Maxwell model. Data for the  $\xi = 1.0$  system gave a similar Cole-Cole plot, i.e., data points also do not fit a semicircle curve. This is similar to the results of Clausen et al. (1992) on a 50 mM CTAC/23 mM NaSal/100 mM NaCl solution. When the NaSal concentration was raised to 26 mM, a better fit to the Cole-Cole semicircle curve was obtained.

#### Extensional viscosity

Apparent extensional viscosities of the surfactant systems were measured (Figs. 15a,b and 16a,b). Figure 15a shows extensional viscosities for Arquad 16–50

(5 mM)/NaSal systems. There is significant increase in the extensional viscosity when the ratio,  $\xi$ , increases from 0.6 to 1.0. The same increase is also observed for Ethoquad O/12 (5 mM)/NaSal systems (Fig. 16a). For Arquad 16–50 systems, the extensional viscosity at  $\xi = 2.5$  is slightly higher at low extensional rates and about the same at high rates as the  $\xi = 1.0$  solution. However, this is not the case for Ethoquad O/12 systems, whose  $\xi = 2.5$  extensional viscosities are surprisingly lower than the  $\xi = 1.0$  values.

The extensional viscosities of Arquad 16–50 solutions decrease with increasing extensional rate above about 50 s<sup>-1</sup> (Fig. 15a). The rate of decrease is approximately the same as that of shear viscosity as shown by

the nearly rate independent extensional to shear viscosity ratios (Fig. 15b). Similar behavior is seen for the Ethoquad O/12 systems (Figs. 16a,b). For  $\xi = 2.5$ , at low extensional rates, both surfactant systems show an extensional viscosity peak before extensional thinning at higher extensional rates. Walker et al. (1996) observed similar increase-peak-decrease behavior on CPyCl (cetylpyridinium chloride)/NaSal systems at 1.4% and 4% concentrations. They suggested that the onset of the increase in extensional viscosity coincides with the onset of nonlinear viscoelasticity, as evidenced by the onset of shear thinning. Because of the low concentrations of our surfactant solutions and the limitations of the rheometers, we could not identify the onset point of shear thinning in most cases.

When  $\xi \geq 1.0$ , the ratios of apparent extensional viscosity to shear viscosity shown in Figs. 15b and 16b are around 100–300, well above 3.0 which is the value for Newtonian fluids. For  $\xi = 0.6$ , this ratio is less than 20. The significant differences correspond to differences in drag reduction of these surfactant systems (Figs. 10a and 10b). Lu et al. (1997a,b, 1998) have shown that high apparent extensional viscosity/shear viscosity ratio values are generally observed for good drag reducing systems.

## Discussion

The results show that rheology, drag reduction and microstructure are dependent on the counterion-to-surfactant ratio. Cationic surfactant headgroups possess positive charges. When the surfactant molecules come together to form micelles, these headgroups are close to each other, and the electrostatic repulsion between the headgroups tends to induce high curvature structures. Thus, without the presence of strongly binding counterions, the micelles are either spherical or form very short cylinders, which do not form networks and cannot give good drag reduction. With the addition of sufficient quantities of certain counterions that bind strongly to the surfactant, the charges on the surfactant headgroups are neutralized and very long micelles can be formed. The non-polar portion of counterions such as salicylate actually penetrates into the hydrophobic region of the micelle (Smith et al., 1994a).

In the case where the number of strongly binding counterion molecules is smaller than the number of surfactant molecules, surfactant headgroups possess net positive charges and electrostatic repulsion between the headgroups makes the rod-like micelles unstable. This is confirmed by the data for the  $\xi = 0.6$  solutions, which have low extensional viscosity, low  $N_1$ , no overshoot in shear experiments and low drag reduction. Cryo-TEM images of the Arquad 16–50 systems show that solutions at  $\xi = 0.6$  have no micellar network. The

thread-like micelles formed in this case may form networks under shear, but they are apparently easily broken up in regions of high shear.

When  $\xi \geq 1$ , the situation is totally different. There are enough counterion molecules to neutralize the charges on the headgroups resulting in more stable micelles. The solutions have high extensional viscosities and high  $N_1$ , show significant overshoot in shear and normal stress and good drag reduction. Thus, there must be differences in the network structure, as supported by the cryo-TEM images of the Arquad 16–50 systems (Figs. 11a,b,c). However, cryo-TEM images of the Ethoquad O/12 systems (Figs. 12a,b,c) do not reveal any difference. Similarly, Clausen et al. (1992) observed no microstructure difference on cryo-TEM pictures for CTAC (50 mM)/NaCl (0.1 M)/NaSal systems with  $\xi = 0.25$  to 2.0, while they observed big differences in plateau modulus, relaxation time and zero shear viscosity for those systems.

## Conclusions

Rheology and drag reduction measurement results show that dilute solutions of the quaternary ammonium cationic surfactant/counterion systems, Arquad 16–50 (5 mM)/NaSal and Ethoquad O/12 (5 mM)/NaSal are viscoelastic and drag reducing. The viscoelasticity and the drag reducing effectiveness increase with counterions/surfactant ratio because of the more stable micelle networks formed after increased neutralization of positive charges on the surfactant headgroups by the negative charges of the counterion molecules. While equal molar counterion molecules are enough to neutralize all charges, excess counterion increases the viscoelasticity and drag reducing effectiveness further.

Cryo-TEM pictures confirm the existence of thread-like micelles as well as an entanglement network in most of these surfactant solutions at low concentrations even with the short time that shear was applied during sample preparation. The micrographs for Arquad 16–50 systems also show that the micellar network significantly changes when the ratio increases from 0.6 to 1.0, though Ethoquad O/12 pictures failed to reveal any change in microstructure with change in  $\xi$ .

The solutions with higher than unity ratio are inherently viscoelastic in nature, i.e., no shear is needed to induce network structure. These systems show high  $N_1$  and significant overshoot. For the highest  $\xi$  solutions, there are abrupt increases in viscosity at certain shear rates. These increases are time effects. They result from microstructure rearrangements rather than formation of shear induced structures. Presumably, similar behavior would be observed in lower  $\xi$  solutions at low shear



rates which could not be measured with the available equipment.

For the Arquad 16-50 solutions at low ratio ( $\xi = 0.6$  and  $1.0$ ) and low shear rates, shear is needed to induce micellar network and viscoelasticity as shown by the two-step stress development. High shear promotes micellar network formation and thus has the same function as using a high ratio of counterion.

Increase in the counterion/surfactant ratio has the same effect on the relaxation times of shear stress and

$N_1$  as increase in the shear rates. Both increase in the ratio and in shear rate result in shorter relaxation times.

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**Sans- and LS-studies on drag-reducing surfactant solutions**H. W. Bewersdorff<sup>a</sup>, J. Dohmann<sup>a</sup>, J. Langowski<sup>b</sup>, P. Lindner<sup>c</sup>, A. Maack<sup>c</sup>, R. Oberthür<sup>d</sup> and H. Thiele<sup>a</sup><sup>a</sup> Universität Dortmund, FB Chemie-technik, D-4600, Dortmund, Fed. Rep. Germany<sup>b</sup> EMBL-Ouistation, F-38042, Grenoble, France<sup>c</sup> Institut Laue-Langevin, F-38042, Grenoble, France<sup>d</sup> Institut für Festkörperforschung, D-5170, Jülich, Fed. Rep. Germany

Available online 23 September 2002.

**Abstract**

SANS-measurements of dilute surfactant solutions containing rodlike micelles were performed under laminar and turbulent (drag-reduced) flow conditions in a pipe geometry. Experiments indicate that the increased local stresses in turbulent flow partially break up the micellar structure, leading to a broader length-distribution of the particles and a decrease of the average rod length.

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# The influence of pre-shearing on the elongational behaviour of dilute polymer and surfactant solutions

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## Abstract

Experimental results are presented which provide information about the elongational behaviour of pre-sheared dilute polymer and surfactant solutions. The viscosity behaviour of these pre-sheared solutions is explained on the basis of molecular data and by flow visualization. A rotational viscometer was modified in such a way that the sheared test fluid left the gap of the viscometer through an orifice in the outer cylinder. The flow-rate at a constant pressure drop through the orifice is related to the elongational viscosity of the fluid. The elongational viscosity of dilute polymer solutions increases when a critical shear gradient is exceeded. The critical shear gradient was found to be independent of the polymer concentration. It could be lowered by increasing the molecular weight of the polymer.

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Visualization of the orifice flows were done in a rectangular channel.

A sudden increase of the apparent elongational viscosity, which is found for poly(isobutene) solutions when a certain Deborah number is exceeded, and an increase of the elongational viscosity, which for poly(acrylamide) solutions is independent of the pre-shearing deformation, can both be related to entrance vortices and instabilities of the entrance flow in the orifice. This was confirmed by flow visualization. The surfactant solutions which were used exhibit a sudden increase of the shear viscosity due to the formation of a shear-induced state (SIS) when a critical shear rate is exceeded. In the SIS their elongational viscosity is also increased. However, the Trouton ratio remains at a value of three which is characteristic for Newtonian fluids.

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# The interaction of polymer additives with vorticity (a case study on vortex rings)

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## Abstract

Laminar vortex rings were created in a Newtonian fluid and in dilute and semi-dilute polymer solutions, then impinged normally onto a plane, smooth wall. The interaction of the vorticity of these rings with the boundary layer on the wall is studied. The results show the importance of a combined shear and elongation on the elongational behaviour of dilute polymer solutions. They indicate that a combination of shear and elongation can enhance the reflection of vortices at the wall in turbulent, drag-reduced flows.


**Author Keywords:** elongational flow; polymer solution; shear flow; vortex ring; vorticity

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# Surfactant Drag Reduction

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## I INTRODUCTION

Drag reduction by additives is a flow phenomenon in which the presence of small amounts of an additive in a carrier fluid causes a reduction in the turbulent friction compared with the pure fluid at the same flow rate. The drag reduced flow is still turbulent, however, with a modified structure of turbulence and the additives normally do not cause relaminarization.

A reduction in energy loss in turbulent pipe flow of wood pulp fiber suspensions in water was reported by Forrest and Grierson [1931] more than sixty years ago. This first report of drag reduction went largely unnoticed [Radin, 1974; Nadolink and Haigh, 1995]. Mysels and his associates [Mysels, 1949; Agoston *et al.*, 1954; Mysels, 1971] found that the pressure drop in pipe flow for gasoline thickened by aluminum disoaps was less than that of pure gasoline under the same flow rate. This was the first drag reduction result recognized. Their results were not published until 1949 due to the Second World War. At the First International Rheological Congress (1948), Toms [1949, 1977] reported drag reduction results on dilute solutions of high molecular weight poly(methyl methacrylate) in monochlorobenzene. He observed that at constant pressure gradient, the flow rate could be increased by the addition of the polymer. Drag reduction is sometimes called the "Toms Effect".

Since the first reports of drag reduction, a great number of researchers have worked in this area. Nadolink and Haigh [1995] compiled a bibliography on drag reduction by polymers and other additives. There are over 4,900 references dating from 1931 to 1994.

Polymer solution drag reduction has been studied extensively in both aqueous and hydrocarbon media and a number of excellent reviews on the subject are available [Lumley, 1969; Patterson *et al.*, 1969; Virk, 1975; White and Hemmings, 1976; Frenkiel *et al.*, 1977; Berman, 1978; Sellin *et al.*, 1982a, b; Sellin, 1984; Giesekus *et al.*, 1985; Hoyt, 1985; Giesekus and Hibberd, 1987; Kulicke *et al.*, 1989; Gyr and Bewersdorff, 1995] along with one on surfactants [Shenoy, 1984]. The state of the art is also documented in conference proceedings, Sellin and Moses [1984], Gampert [1985], Rabin

[1985], Sellin and Moses [1989] Gyr [1990] and ASME [1996]. Spectacular commercial success was achieved in increasing crude oil throughput in the Alyeska and other pipelines by injecting concentrated polymer solution into the flowing crude oil at pipeline locations where excessive pressure drops were limiting crude oil flow rates [Burger *et al.*, 1982]. With polymer concentrations of 5 to 25 ppm, flow rates were increased by up to 25% increasing the capacity of the 48-inch Alyeska pipeline by up to 500,000 barrels of crude per day [Burger *et al.*, 1982]. Since the first operation of this large scale application of drag reduction, the polymers have been improved. The increased effectiveness of the additives led to reduction of polymer concentrations by a factor of 12 since 1979 [Motier and Carrier, 1989].

Although Mysels and coworkers showed the effectiveness of aluminum disoaps in gasoline, only a few investigators utilized aluminum soaps in their studies, probably because high polymers were more efficient. That is, they gave larger pressure drop reductions at lower concentrations. The most effective aluminum disoaps were aluminum dioctoate [Lee, 1968; McMillan, 1970; McMillan *et al.*, 1971; Lee and Zakin, 1972; Hershey *et al.*, 1975] and a dialkyl aluminum phosphate [Sylvester and Smith, 1979], the latter showing excellent drag reduction at only 200 ppm.

Unfortunately, both high molecular weight polymers and aluminum disoaps degrade when subjected to high mechanical shear and elongation such as is encountered in most pumps. The polymer chains in polar or non-polar solvents are broken and the smaller segments formed are not effective as drag reducers. This degradation process of the polymers increases with temperature. Polymer degradation is irreversible as there is little chance that the segments could recombine. In the case of aluminum disoaps, which are relatively low in molecular weight, large aggregates are formed and their break-up under mechanical shear is reversible but the reaggregation is generally a slow process taking days to recover their drag reducing ability [Lee, 1968; Lee and Zakin, 1972]. Thus, for recirculation systems where the fluid is continually recycled through a pump, high polymers in either aqueous or hydrocarbon systems and aluminum disoaps in hydrocarbon systems are not suitable as drag reducing additives.

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There are important applications where recirculation of water is desired such as in district heating or district cooling systems. Here hot or chilled water whose temperature is adjusted at a central station is circulated through a district to heat or to cool buildings. The water is returned to the central station for reheating or recooling. Pumping energy costs are an important cost factor in such systems and the use of drag reducing additives to reduce these costs may be an attractive application for such additives. Thus, there has been considerable interest in recent years in finding non-degrading or rapidly repairable additives which would be effective for long times in such recirculation systems.

In this paper, we limit ourselves to review of drag reduction by surfactant additives. Though research on surfactant drag reducers didn't gain momentum until the 1980's, a considerable number of publications can be found in the literature. Interest in these systems is mainly due to their self-repairability. That is, surfactant micelle microstructures, which are necessary for drag reduction, can repair themselves in a time scale of the order of seconds after passing through a region of high shear or high extension rate. Thus, surfactant drag reducers have potential applications in recirculating flow systems or multi-pump station pipeline flow systems.

## II SURFACTANT SOLUTIONS

### 2.1 Characteristics of Surfactant Solutions

Surfactants are characterized by the coexistence of a hydrophobic "tail" and a hydrophilic head group in one molecule and are referred to as amphiphilic compounds. The hydrophobic tail is generally a long chain alkyl group, whereas the hydrophilic head of the molecule is ionizable, polar, polarizable or suitable for forming hydrogen bridges. For surfactants in an aqueous environment, the hydrophilic groups like to reside in the water phase and the hydrophobic groups try to leave the water phase. There are two ways to avoid the unfavorable hydrophobic group-water contact. One way is for the hydrophobic groups to orientate themselves into a nonpolar phase, such

as a gas phase, a non-polar solid or a hydrophobic liquid phase. Another choice is self association, that is, for surfactant molecules to form assemblies called micelles in which the non-polar portions concentrate in the center while the polar ends lie on the surface in contact with water. Micellization is a feature of surfactant solutions above their critical micelle concentration (CMC). Above the CMC the micelles are always in thermodynamic equilibrium with the monomer molecules.

A simplified phase diagram for aqueous surfactant solutions is shown in Fig. 1. When the temperature is lower than the so-called Kraft point, the surfactant is partially in crystal or gel form in the solution. For temperatures higher than this point, surfactant molecules aggregate together to form spherical micelles when the concentration exceeds the CMC, and rod-like micelles are formed when the concentration further increases to exceed the  $CMC_{II}$ . One can see from Fig. 1 that the CMC is almost independent of temperature, while the  $CMC_{II}$  increases with temperature.

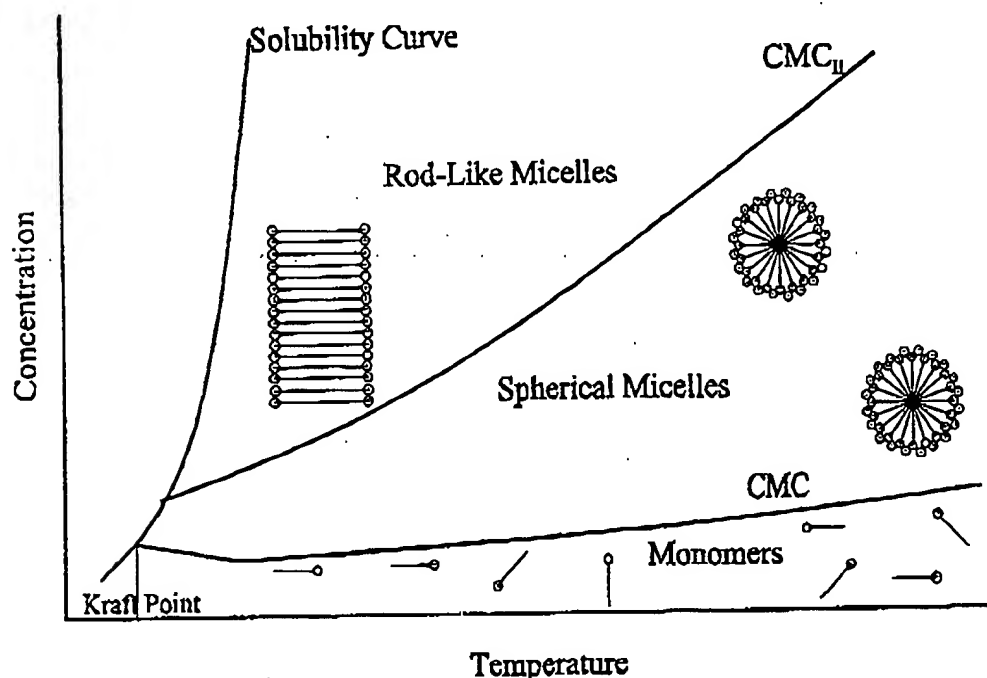


Fig. 1: Schematic phase diagram for surfactant solutions [Lu, 1997c].



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Surfactants can be grouped into two broad classes by their hydrophilic or polar groups: ionics and nonionics. Ionics can be further divided into two subclasses namely, anionics and cationics, and nonionics have three subclasses: zwitterionic, semipolar and single-bond subclasses [Laughlin, 1991].

## 2.2 Micelle Shape

The major types of micelles are (1) spherical; (2) rod-like; (3) lamellar; (4) vesicles [Rosen, 1989]. Micelles are believed to be of spherical or roughly spherical shape at the CMC. Tanford [1972] proposed that small micelles are ellipsoidal rather than spherical in shape. He believed that the ellipsoidal shape can incorporate a larger number of hydrocarbon chains in a micelle and he provided a calculation for the shape of ellipsoids necessary for aggregation numbers up to 570. He suggested that amphiphiles with a single hydrocarbon chain per polar head group form micelles with ellipsoidal or spherical shapes.

Regardless of the shape of the micelle at the CMC, when the concentration is increased to  $CMC_{II}$ , rod-like micelles are formed in the solution. Evidence to support the existence of rod-like or elongated micelles has been provided by a number of investigators using different experimental techniques over the years [Debye and Anacker, 1951; Young *et al.*, 1978; Porte *et al.*, 1980; Ikeda *et al.*, 1981; Lindner *et al.*, 1990]. Debye and Anacker [1951] studied the cetyltrimethyl ammonium bromide/potassium bromide (CTAB/KBr) system using static light scattering and found that the micelles are not spherical or disk-like in shape, and the data indicate they are rod-like. Porte *et al.* [1980] combined results from magnetic birefringence, quasi-elastic light-scattering spectra and NMR measurements on 6 mM cetylpyridinium bromide with various amounts of NaBr and NaCl (0-0.8M), and concluded that the micelles in that solution are semiflexible rods. Young *et al.* [1978] studied a 2g/L aqueous solution of sodium dodecyl sulfate (SDS) in 0.6 M NaCl using light scattering and concluded that the micelles in

this solution were rod shaped. The angular dependence of light scattering, observed by Ikeda *et al.* [1981], indicated that the large micelles formed in sodium dodecyl sulfate (SDS) with sodium halide solutions are rod-like. Experimental results from NMR also indicated that CTASal micelles are rod-like in shape [Olsson *et al.*, 1986]. More recently, Lindner *et al.* [1990] detected rod-like micelles of average length 249 nm in a 2.4 mM tetradecyltrimethyl ammonium salicylate ( $C_{14}$ TASal) in heavy water ( $D_2O$ ) system by small angle neutron scattering and light scattering methods. He suggested that amphiphiles with a single hydrocarbon chain per polar head group form micelles with ellipsoidal or spherical shapes:

Recent developments in cryo-transmission electron microscopy (cryo-TEM) techniques have made it possible for researchers to get direct images of micellar structures without altering the structures in sample preparation. Rod-like or worm-like micelles have been observed in various surfactant/salt systems [Bellare *et al.*, 1988; Vinson and Talmon, 1989; Walter *et al.*, 1991; Clausen *et al.*, 1992; Cochin *et al.*, 1992; Lu *et al.*, 1996a, b, c, d; Lu *et al.*, 1997a, c; 1998]. Lu *et al.* [1996a, b, c, d; 1997a, c; 1998] showed very long worm-like micelles and entangled micellar networks for drag reducing cationic surfactant solutions, while only spherical micelles were observed for non-drag-reducing surfactant systems.

Israelachvili *et al.* [1976] developed a theory of micellar structure. Considering a surfactant with an alkyl chain length,  $l$ , a volume of alkyl chain in the micelle core per molecule,  $V$ , and a cross sectional area of headgroup per molecule,  $a$ , the value  $V/la$ , the packing parameter, determines the shape of the micelles (Table 1).

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Table 1  
Micelle Shape for Different  $V/la$

Value of $V/la$	Shape of the Micelle
0-1/3	Spherical
1/3-1/2	Rod-like
1/2-1	Lamellar
>1	Reversed micelles in nonpolar media

Tanford [1972] established the equations to calculate the volume occupied by an alkyl chain of  $N$  carbon atoms embedded in the hydrocarbon core,  $V$ , and the maximum possible extension of a hydrocarbon chain,  $l_{max}$ :

$$V = 27.4 + 26.9N (\text{\AA}^3) \quad (1)$$

$$l_{max} = 1.5 + 1.265N (\text{\AA}) \quad (2)$$

For spherical micelles, the maximum micelle aggregation number can be uniquely determined from these two equations [Tanford, 1972].

Tanford [1972] and Israelachvili *et al.* [1976] pointed out that regardless of the shape of the micelles, no point within the micelle can be farther from the hydrocarbon-water interface than  $l_{max}$ . It is equivalent to say that at least one of the three dimensions of the micelles must not exceed  $2l$  to ensure an aqueous environment for the polar heads. Thus, the radius of the spherical micelles is approximately equal to  $l_{max}$ . For rod-like micelles, the radius of the rod should be approximately  $l_{max}$ . To accommodate packing in the hydrocarbon core,  $l$  is usually less than  $l_{max}$ .

The addition of salts, co-surfactants or counterions can also induce the formation of rod-like micelles [Ohlendorf *et al.*, 1986a]. All of these additives can neutralize or disperse the electrostatic repulsion between the ionic headgroups, stabilize the micelle and promote formation of large micelles.

### 2.3 Micelle Size

The size of the micelle depends on many factors, including the chain structure of the surfactant, the head group of the surfactant, counterions, added salts and temperature, etc. From geometric considerations, one can expect that the aggregation number of spherical micelles will increase with the hydrocarbon chain length of the surfactant and decrease with increase in the hydrophilic head group size [Rosen, 1989] and, it has been observed that the micelle aggregation number increases rapidly with increase of hydrocarbon chain length and decreases with increasing cross-sectional area of the headgroup [Wennerstrom and Lindman, 1979]. Geer *et al.* [1971] found in their light scattering studies that decylammonium bromide gives the largest micelle weight while decyltriethylammonium bromide gives the lowest micelle weight. They suggested that larger headgroups tend to keep the counter-ions from approaching the charge center and thus are not favorable for micellar growth. Rehage and Hoffmann [1991] explained the headgroup effects on micelle shape based on geometrical considerations. If the hydrophilic head group requires an area larger than the corresponding cross section of the hydrocarbon chain, the system will tend to form aggregates with convex curvatures. If both sizes are the same, planar structures are favored. If the head group needs an area less than that of the hydrocarbon chain, inverse micelles will be formed.

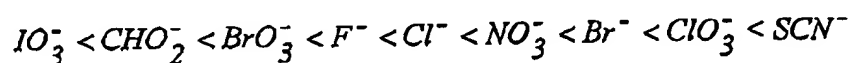
The length of rod-like micelles has been shown to increase with increase in surfactant concentration and decrease in temperature [Missel *et al.*, 1980, 1983; Elson and Garside, 1983; Hoffmann *et al.*, 1985b; Myska *et al.*, 1997]. Missel *et al.* [1980, 1983] measured rapid increases of the aggregation number and the hydrodynamic radius of micelles with increasing surfactant concentration. Based on their measurements of drag reduction and swirl decay time (SDT) on cationic surfactant/1-naphthol systems, Elson and Garside [1983] suggested that the rod-like micelles are longest and strongest around the surfactant Kraft point. Hoffmann *et al.* [1985b] found the rod length increases linearly with increasing concentration to a peak and then begins to decrease. The concentration for the maximum rod length is noted as  $c^*$ . It was believed that at  $c^*$ , the length approaches the mean distance

between the rods. It should be mentioned that  $c^*$  increases with decreasing length of the alkyl chain length. The aggregation number may be very large at some moderate concentration. Strivens [1989] calculated the aggregation number for 0.1 M CTAB-SA (salicylic acid) solution to be about 5000 at 25°C from rheological measurement results. This is equivalent to a micellar weight of 2,000,000. Myska *et al.* [1997] found in their light scattering studies on cationic surfactant drag reducing solutions that the micelle size increases with the concentrations of surfactant and of counterion. They also found that length of rod-like micelles in Habon G (cetyl dimethyl hydroxyethyl ammonium 3-hydroxy-2-naphthoate) solutions are about four times those of Ethoquad T/13-50 (tallow tris-hydroxyethyl ammonium acetate) / sodium salicylate and Arquad 16-50 (cetyl trimethyl ammonium chloride) / sodium salicylate solutions at 5 mM concentration.

Salts play an important role in affecting micellar growth. This is because micelle formation is strongly controlled by the positive charges on cationic surfactant headgroups. Salts with greater ability to neutralize these charges will certainly favor both micellar formation and growth [Rosen, 1989].

Ohlendorf *et al.* [1986b] studied the effect of the addition of salts on the length of the rod-like micelles for cationic surfactants. Their results showed that the length first increases with salt concentration reaching a peak and then decreases. They found that the higher the valence of the anionic ions, the more effective are the salts. Bewersdorff and Ohlendorf [1988] and Myska *et al.* [1997] found that rod-like micelles are longer in tap water than those in deionized water, which they interpreted as an effect of the salts in the tap water.

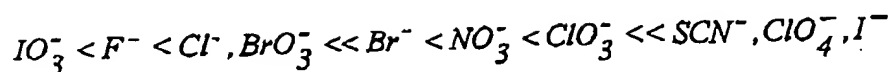
In general, the effectiveness of salt on the aggregation number of rod-like micelles increases with increasing lyotropic number of the anion. Anacker and Ghose [1963, 1968] reported the order of effectiveness in increasing the aggregation number for dodecyltrimethyl ammonium micelles is:



and for cetylpyridinium micelles:

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For aromatic acid anions, Rehage and Hoffmann [1991] concluded from their studies of the effects of benzoate with different counterions on the viscosity of the solution that the micellar growth is induced by two different processes: a change in the packing parameters (area/volume ratio) and a reduction of the surface charge. Aromatic acid anions are known to be absorbed at the micellar interface. The degree of penetration depends on the nature and position of the substituent groups on the phenyl ring. With different degrees of penetration, the degree of change in the packing parameters and the reduction of the surface charges are different.

Gravsholt [1976] suggested that organic counterions of great importance are salicylate, m-chlorobenzoate and p-chlorobenzoate. With the presence of a few millimoles per liter of salicylate, rod-like micelles several hundred angstroms in length were detected at a few millimoles per liter of cationic surfactant solution [Hoffmann *et al.*, 1984a; 1985a; Lindner *et al.*, 1990]. Rehage and Hoffmann [1991] found that while p-toluic acid (4-methyl-benzoate) can greatly increase the solution viscosity, the o-toluic acid has no effect on the viscosity, and the m-toluic acid has an intermediate effect. They concluded that the viscoelasticity not only relates to the binding, but also to the specific orientation of the added compounds. Smith *et al.* [1994] found in their NMR studies of substituted benzoates that the counterions tend to orient their substituent group to a favorable environment if the structure allows it, i.e., the hydrophobic chloro or methyl groups into the micellar phase and the polar hydroxy group into the water phase. Drag reduction effectiveness strongly correlates with the positions and the orientations of substituent groups on the phenyl ring of different counterion isomers, i.e., 4-chloro-benzoate and 4-methyl-benzoate are more effective than their 2 position isomers and salicylate (2-hydroxy-benzoate) is more effective than 4-hydroxy-benzoate [Chou, 1991b]. It is generally agreed that drag reduction ability is related to the existence and the size of rod-like micelles. Thus, the results by Smith *et al.* [1994] also imply a relation between the orientation of counterions and the micellar size, a result confirmed by line broadening in the NMR data.

### III. SURFACTANT DRAG REDUCTION

Four types of surfactants have been investigated for drag reduction, namely anionic, cationic, nonionic and zwitterionic. Anionic soaps have proven to be good drag reducers and mechanically stable [Savins, 1967]. However, their applications are limited due to precipitation of the salts formed with calcium and magnesium ions normally present in tap and sea water [Zakin *et al.*, 1971]. Other problems may arise due to their strong tendency to form foams with air. Nonionic and cationic surfactants are both less sensitive to cations. However, nonionic surfactants are generally effective as drag reducers only in a narrow temperature range around the cloud point of the surfactant [Zakin and Lui, 1983]. This may not be a serious problem in district cooling systems which operate in a narrow temperature range. Drag reduction of zwitterionic surfactants has only been reported recently [Harwigsson, 1995; Harwigsson and Hellsten, 1996; Hellsten *et al.*, 1996] in combination with an anionic surfactant (sodium dodecylbenzene sulphonate). Cationic surfactants, on the other hand, show much broader effective temperature ranges [Chou, 1991b] and thus may have more potential applications. In the following sections, the four kinds of surfactant drag reducers will be reviewed with emphasis on cationics.

#### 3.1 Fundamental Concepts in Drag Reduction

In this section, some fundamental definitions and formulae for pipe flow and drag reduction will be introduced.

When fluid flows through pipes or channels, a certain amount of power is needed to overcome the wall friction. By a force balance, the wall shear stress in a fully developed pipe flow is related to the pressure drop by the following equation:

$$\tau_w = \frac{\Delta P D}{4L} \quad (3)$$

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where  $\Delta P$  is the pressure drop,  $D$  the pipe diameter and  $L$  the pipe length. A similar relationship based on a force balance can be obtained for channel flows.

The Fanning friction factor is defined as:

$$f = \frac{\tau_w}{\frac{1}{2} \rho V^2} \quad (4)$$

where  $V$  is the mean flow velocity and  $\rho$  is the density. Substitution of Eq. (3) into Eq. (4) leads to:

$$f = \frac{\Delta P D}{2 \rho V^2 L} = \frac{\pi^2 D^5 \Delta P}{32 \rho L Q^2} \quad (5)$$

where  $Q$  is the volume flow rate.  $f$  can be calculated if  $\Delta P$  and  $Q$  are measured.

The Reynolds number for pipe flow for Newtonian fluids is defined by:

$$N_{Re} = \frac{\rho V D}{\mu} = \frac{4 \rho Q}{\pi \mu D} \quad (6)$$

where  $\mu$  is the viscosity. Polymers, like polyethyleneoxide or polyacrylamide, exhibit drag reduction at such low concentrations that the deviations in the shear viscosity compared to that of the solvent can be neglected. Some drag reducing surfactant solutions exhibit significant increases in shear viscosity. Thus, in a physical analysis of the flow properties the change in viscosity of these solutions cannot be neglected. However, for ease of comparison of drag reducing flows and carrier fluid or solvent flows, the solvent physical properties are generally used to calculate  $N_{Re}$  and  $f$  in the above equations when applied to drag reduction.

With the addition of an additive to a turbulent flow system, drag reduction occurs if, at the same flow rate, the pressure drop is reduced or at the same



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pressure drop, the flow rate is increased. It is common to define drag reduction at constant flow rate as:

$$\%DR = \frac{f_s - f}{f_s} \times 100 \quad (7)$$

where %DR is percentage drag reduction and  $f$  and  $f_s$  represent the friction factors of the solution and the solvent respectively at the same flow rate.  $f_s$  can be calculated by the von Kármán equation (Eq. 8) or directly measured in the drag reduction system for solvent flow.

$$f^{-1/2} = 4.0 \log(N_{Re} f^{1/2}) - 0.4 \quad (8)$$

A fluid is drag reducing if the %DR is positive; the greater the value, the more effective it is. According to Eq. (7), values of %DR could lie between 0 and 100, but 80-90% is normally the maximum.

The measurement of drag reduction is straightforward. The pressure drop over the test section and flow rate through that section are the two quantities that need to be measured. Then calculation of drag reduction can be made following the above equations. Three different formats have been used to present data: one is to plot %DR against  $\log N_{Re}$ , another is to plot  $\log f$  against  $\log N_{Re}$ , and the third is to plot the data as  $f^{-1/2}$  vs.  $\log(N_{Re} f^{1/2})$ . The von Kármán line according to Eq. (8) is generally plotted in the latter two for comparison.

### 3.2 Drag Reduction of Anionic Soap Solutions

Savins [1967, 1968, 1969] obtained more than 80% drag reduction using 0.2% sodium oleate in water with KCl. Increasing KCl concentration from 3.5 to 10% increased drag reduction from 45% to 82%. He suggested that with increasing electrolyte concentration, spherical micelles were probably rearranged into cylindrical micelles which formed a network of interlaced rod-like elements.

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### *Surfactant Drag Reduction*

Savins also noted that when the wall shear stress exceeded a critical stress, drag reduction dropped to zero, but the process was reversible, i.e., drag reduction was regained when the shear stress was lowered. The loss of drag reduction was presumably caused by break-up of the micelle microstructure due to high shear stresses. The rate of break-up was faster than the rate of reformation. The recovery of drag reduction when the flow rate was lowered showed that the micelle microstructure reformation rate exceeded the rate of break-up. No permanent degradation was noticed after 88 hours of continuous shear above the critical wall shear stress. These findings are important for surfactant drag reduction applications and were also observed for cationic surfactants. The problem with anionic soaps is their sensitivity to  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  normally found in tap water and sea water which cause precipitation. Furthermore, anionic surfactants exhibit a strong tendency to form foams with air which can cause additional problems in applications.

#### **3.3 Drag Reduction of Nonionic Surfactant Solutions**

Nonionic surfactant molecules don't carry charges and thus they are less affected by other ions. This property is an advantage for nonionic surfactants as drag reducers as they will not be inordinately affected by calcium and magnesium ions normally present in tap water. Nonionic surfactants also have unique upper coacervation temperatures or cloud points at and above which the surfactant-water systems separate into two phases.

Zakin and coworkers were pioneers in investigating the drag reduction effectiveness of nonionic surfactants [Zakin and Chiang, 1972; Zakin and Lui, 1983; Chang and Zakin, 1985; DeRoussel, 1993]. They observed that nonionic surfactants with straight chain alkyl groups ( $\text{C}_x\text{H}_y\text{-(OCH}_2\text{-CH}_2)_z\text{-OH}$ , where  $x$  is 12 to 18,  $y$  is  $2x+1$  or  $2x-1$  and  $z$  is about  $0.5x$ ) were effective while alkyl phenyl surfactants were not. Chang and Zakin [1985] discovered that some mixtures of nonionic surfactants at 1% concentration with the chemical structure of  $\text{C}_{18}\text{H}_{35}\text{-(OCH}_2\text{-CH}_2)_n\text{-OH}$  were effective drag reducers at temperatures just below and above their cloud point temperatures. They found that the addition of sodium sulfate or of

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phenol lowered the cloud point and increased the relative viscosity. Thus the drag reducing ability at temperatures below the normal cloud point is enhanced upon the addition of the salt or phenol as the cloud point was lowered to approach the measurement temperature [Chang and Zakin, 1985]. Their surfactant systems appeared to be mechanically stable. Mechanically degraded solutions quickly regained their reducing ability upon entering a low shear region, i.e. after passing through a pump [Zakin and Lui, 1983].

DeRoussel [1993] performed drag reduction measurements on a number of nonionic surfactants containing saturated and unsaturated  $C_{12}$  to  $C_{18}$  alkyl groups with 4 to 23 ethylene oxide groups at 1% concentration. The conclusions he reached are that the temperature at which maximum drag reduction is observed is close to the cloud point (coacervation temperature) of the surfactant solution. At least 20% drag reduction was observed at temperatures 10 to 25°C above and below the cloud point temperature. Increase of the length of the alkyl group and decrease in the number of ethylene oxides both decreased the cloud point and the effective temperature range for drag reduction. Further, mixed nonionic surfactants have cloud points intermediate between those of the pure surfactants. Thus, selection of the length of the alkyl chain, the number of ethylene oxide groups, and the constituents and concentrations of mixed surfactant systems can be used to affect the cloud point and hence the potential temperature range in which a surfactant system would be effective for drag reduction. This does not guarantee the surfactant system selected will be effective in the temperature range, but it does provide a guide for rapid screening of possible additives for a particular application with a defined temperature range. Minor adjustments can also be made by considering the saturation or unsaturation of the alkyl group. Unsaturation will shift the cloud point to a higher temperature compared with a saturated alkyl group. A measurement on a mixture of nonionic and cationic surfactants was also carried out in the same study. However, the level of drag reduction was below that of the nonionic surfactant alone.

Hellsten and Harwigsson [1994] tested a nonionic surfactant for drag reduction effectiveness. The surfactant was ethoxylated fatty acid

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ethanolamide,  $C_nH_{2n-1}CONHC_2H_4(OC_2H_4)_mOH$ . Two main groups, RMA-m ( $n=22$ , from rapeseed monoethanolamide) and OMA-m ( $n=18$ , from oleic acid monoethanolamide), were investigated. They found that RMA-3, RMA-6, RMA-8 or their mixtures and OMA-5 were effective in different parts of the temperature range from 6 -35 °C. The RMA's were effective at the high end of the range and OMA was effective at the low end. Lu *et al.* [1997b] reported that OMA-3/4 was effective from 1°C to 15°C. The concentrations used in these studies ranged from 2000 ppm to 6000 ppm. Biodegradability and toxicity data were also provided to show that this kind of surfactant is rapidly biodegradable and has low toxicity against marine organisms [Hellsten and Harwigsson, 1994]. They suggested that this kind of surfactant may be a good candidate for applications in district cooling systems which operate at 5 to 15 °C.

### 3.4 Drag Reduction of Zwitterionic Surfactant Solutions

Zwitterionic surfactants have both positive and negative charges in one surfactant molecule and thus form a special kind of nonionic surfactant [Laughlin, 1991]. Recently, Harwigsson [1995], Harwigsson and Hellsten [1996] and Hellsten *et al.* [1996] studied zwitterionic surfactants, N-alkylbetaines ( $CH_3(CH_2)_n - N^+(CH_3)_2CH_2COO^-$ ,  $n = 15$  or 17) with 5-15% (mol.) of sodium dodecylbenzenesulphonate (Na-LAS). They found that the  $C_{16}$ -betaine (2.5 mM) / Na-LAS (0.5 mM) system is drag reducing between 8 and 50 °C and the  $C_{18}$ -betaine (2.5 mM) / Na-LAS (0.5 mM) system between 30 and 85 °C. They also studied the effect of this kind of surfactant system on heat transfer. A reduction up to 21% was measured for overall heat transfer in a plate heat exchanger. The betaines are considered readily biodegradable and less toxic to marine organisms than many cationic surfactants. However, since zwitterionic surfactants have both positive and negative charges in a single surfactant molecule, they may be sensitive to ions existing in water or present in the flow system. Thus, their stability in the presence of anions and cations needs to be investigated.

### 3.5 Drag Reduction of Cationic Surfactant Solutions

The narrow temperature range for effective drag reduction limits the usefulness of nonionic surfactants as drag reducers, and precipitation caused by calcium and magnesium ions found in tap water limits the applications of anionic soap surfactants. Drag reduction data on zwitterionic and nonionic systems are sparse. Cationic surfactants generally have fairly wide temperature ranges and are not very sensitive to calcium or magnesium ions. Because of their potential for applications, extensive research on cationic surfactant drag reducing additives has been carried out over the last ten years. Research in this area will be reviewed in a systematic manner in the following sections.

#### 3.5.1 Surfactant Structure Effects

Quaternary ammonium surfactants and those with related structure (cetyl pyridinium salicylate or CPySal) have excellent drag reduction abilities. Cetyl trimethyl ammonium bromide (CTAB) was the first cationic surfactant to receive attention in drag reduction studies [White, 1967; Zakin *et al.*, 1971]. White [1967] studied 508 ppm CTAB with equi-molar 1-naphthol. No onset phenomenon was observed but rather a gradual departure from the laminar line. He found that drag reduction terminates at a fixed wall shear stress which was independent of diameter. He called that stress the critical wall shear stress. Zakin *et al.* [1971] studied 1500 ppm CTAB with varying amounts of 1-naphthol. They found that drag reduction increased with the Reynolds number to a maximum of about 70% and then decreased to zero when the wall shear stress exceeded the critical shear stress. They suggested that at this point, the forces causing the soap to aggregate are overcome by the shear stress so the aggregates are broken down to small particles which have little drag reduction ability, similar to Savins' proposal for anionic surfactant aggregates.

Chou *et al.* [1987, 1988] reported drag reduction results on three cationic surfactant systems:  $C_{16}TAC$  (CTAC),  $C_{18}TAC$  and  $C_{22}TAC$  (ETAC). All surfactants were at 2000 ppm with 2000 ppm sodium salicylate as counterion. They reported the effective drag reduction temperature ranges are 30 to 60°C,

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30 to 90°C and 60 to 110°C for the C<sub>16</sub>TAC/NaSal, the C<sub>18</sub>TAC/NaSal and the C<sub>22</sub>TAC/NaSal systems, respectively, independent of tube diameters in 0.106-inch, 0.243-inch and 0.824-inch pipes. Effective drag reduction at 80, 93 and 107 °C was also observed for the C<sub>22</sub>TAC (ETAC) system in a 6-inch pipe. Thus, they concluded that there is an upper temperature limit for effective drag reduction which is dependent on the alkyl chain length [Chou *et al.*, 1988]. Rose *et al.* [1984, 1989] also reached the same conclusion. Above the maximum critical temperature, the solutions lose their effectiveness, but regain it when cooled below the critical temperature. These conclusions were confirmed in later studies on other alkyl trimethyl ammonium chlorides, alkyl bis-hydroxyethyl methyl ammonium chloride and alkyl tris-hydroxyethyl ammonium chloride surfactants with different alkyl chain lengths [Chou *et al.*, 1989a; Chou, 1991b].

Rose *et al.* [1984, 1989] and Chou *et al.* [1989a] also found that the lower temperature limit depends on solubility of the surfactant. Surfactants containing alkyl bis-hydroxyethyl methyl are more hydrophilic than those with alkyl trimethyl and thus the former can provide drag reduction down to lower temperatures, such as 2°C (the lowest temperature they tested). Unsaturation of the alkyl chain also improves the solubility of long chain surfactants and thus provides the possibilities for them to be drag reducing at low temperature [Rose *et al.*, 1984, 1989; Chou *et al.*, 1989b].

Chou and Zakin [1991a, b] also studied the drag reduction effectiveness of mixed cation and mixed counterion cationic surfactant systems. The mixed surfactants are dodecyl (C12) trimethyl ammonium chloride / erucyl (C22) trimethyl ammonium chloride (DTAC/ETAC), and dodecyl trimethyl ammonium chloride/cetyl (C16) trimethyl ammonium chloride (DTAC/CTAC). They noted that the effective drag reduction temperature range for long chain cationic surfactants usually extends to high temperatures and the short chains are only effective at low temperatures. However, when a long chain surfactant was mixed with a short chain surfactant, the temperature range was extended. The addition of a small amount of short chain surfactant greatly depressed the lower temperature limit of the long chain surfactant, while its upper temperature limit could be maintained at a high level. Thus, it

is possible to have cationic surfactant systems with a temperature range wide enough to cover temperatures involved in both district cooling and district heating systems. In the same study, they also explored the effect of mixed counterions. In general, the results were similar but the effect was smaller.

### 3.5.2 Counterion Effects

Generally, without strongly binding counterions or other additives, cationic surfactants would not form rod-like micelles necessary for drag reduction at low concentrations such as less than 1%. Thus, it is necessary to add certain kinds of strongly binding additives to cationic surfactant solutions for drag reduction.

The first additive to receive wide attention was 1-naphthol. After White's [1967] research, several other researchers investigated the cationic surfactant/1-naphthol system. As noted above, Zakin *et al.* [1971] studied 0.15% CTAB with varying amounts of 1-naphthol. They found that the highest critical shear stress (maximum shear stability) occurred when the weight ratio of CTAB to 1-naphthol was 2.1 to 1 (1:1 molar ratio).

Various alkyl trimethyl ammonium halides with 1-naphthol were studied by Elson and Garside [1983]. The 1-naphthol concentration effect was studied by them. They believed that due to the solubility of the 1-naphthol, at low concentrations the additive has to be more than equimolar with the surfactant in order to offset part of the 1-naphthol which was dissolved in the water. At high surfactant concentrations, however, the effect is small. Thus, the optimum ratio of additive to surfactant will be one to one for high concentrations, while it should be higher than one to one for low concentrations of surfactant.

Gravsholt [1976] suggested that the counterions of great importance are salicylate, m-chlorobenzoate and p-chlorobenzoate. Extensive drag reduction tests with sodium salicylate as counterion were performed [Chou *et al.*, 1987, 1988, 1989a, 1989b, 1991a, 1991b; Gasljevic, 1995a]. Chou *et al.* [1989b; 1991b] studied the 5 mM Ethoquad O-12 (oleyl bishydroxymethyl ammonium chloride) system with various amounts of sodium salicylate. They found that at 2 °C with a 1.5:1 ratio of counterion, the surfactant system showed the highest critical wall stress, i.e., this ratio gave the most effective

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drag reduction system at this temperature. Rose *et al.* [1984, 1989] found that excess quantities of salicylate give a higher critical temperature and higher critical Reynolds number for loss of drag reduction for the CTASal system. They found that a CTASal solution with excess salicylate maintained effective drag reduction activity for 10 weeks in their district heating study at temperatures between 40 and 90 °C. For hydroxynaphthoates as counterions, however, excess counterion reduces the drag reduction efficiency [Chou, 1991b]. He suggested that the rod-like micelles become more rigid in this case.

The influence of the counterion on the friction behavior of a C16TA-system was studied by Ohlendorf *et al.* [1986a]. The counterions were -Sal, -SCN,  $-C_3F_7COO$ ,  $-C_7F_{15}SO_3$  and -3-OH-2-naphthoate. With the same surfactant, the different counterions produced changes in friction behavior as significant as those produced by changes in the hydrocarbon chain length or the temperature.

Chou *et al.* [1989a] proposed that while salicylate is the most widely used counterion, other counterions may also be very effective. The existence of a hydrophobic substituent group on benzene or naphthalene compounds may promote more effective drag reduction systems as long as they are separated from other hydrophilic substituent groups on the same ring. Later, through NMR studies, Smith *et al.* [1994] confirmed that the position of substituent groups on the phenyl and naphthoate ring can affect the orientation of counterion molecules at the micelle-water interface. If a hydrophobic group adjacent to a carboxylate must reside in the water phase, then no stable rod-like micelles can be formed and correspondingly, no drag reduction occurs. The influence of the counterion concentration on the aggregation behavior of viscoelastic micellar systems was systematically studied by Hoffmann *et al.* [1981].

An intriguing phenomenon observed in cationic surfactant drag reduction is the so-called "gap phenomena" [Chou, 1991b; Kleuker *et al.*, 1991]. When Chou [1991b] measured drag reduction for a 2.85 mM Habon (hexadecyl trimethyl ammonium-3-hydroxy-2-naphthoate) plus 9.375 mM NaSal, he found no drag reduction at 50 °C, while at 30, 40, 60 and up to 100 °C this system showed good drag reducing ability. A similar observation was



reported by Kleuker *et al.* [1991] when they studied the drag reduction of a Dobon-G (docosyl dimethyl hydroxyethyl ammonium-3-hydroxy-2-naphthoate) plus NaSal solution in a large scale system. They found the drag reduction effect was lost in a middle temperature range (from 60 to 80 °C) after a few days of operation, while the solution was effective from 40 to 130 °C in laboratory tests (the details were not reported). They explained this as due to biological contamination by protein. Both surfactant systems involved here have 3-hydroxy-2-naphthoate as counterion plus excess sodium salicylate. Chou [1991b] explained the "gap" phenomenon as the result of the competition between the 3-hydroxy-2-naphthoate and the salicylate. He postulated that at certain temperatures, they canceled each other's effectiveness. Kleuker *et al.* [1991] also mentioned that Dobon-G normally features a quite narrow temperature span in drag reduction from 100 to 140°C. The addition of the NaSal shifted the effective temperature range to 40 to 130°C. They suggested that the salicylate counterions probably replaced the naphthoate counterions at the surface of the micelles at lower temperatures. However, as noted above, in their laboratory tests, no gap phenomenon was observed. These anomalous results have not been further studied.

### 3.5.3 Stability

It is generally believed that cationic surfactant drag reducers are stable. Early studies on cationic surfactant drag reduction found that cationic surfactants show no mechanical degradation although the 1-naphthol systems were chemically unstable and deteriorated in days [White, 1967; Zakin *et al.*, 1971]. Rose *et al.* [1984, 1989] found that a 0.2% CTASal drag reducing solution was stable over a time period of 2.5 months.

However, recent research has shown that a cationic surfactant, Ethoquad T/13-50 / NaSal, may not be stable with time [Lu *et al.*, 1995; Gasljevic, 1995a; Hu and Matthys, 1997a]. Drag reduction was completely lost after several days. This contradicts earlier data by Chou [1991b] on the same surfactant system which showed no loss of drag reduction after 11 days. The degradation may have been due to interactions of the surfactant or salicylate molecules with different materials in the flow system and/or adsorption of the

surfactant molecules on the inside wall of the flow system [Lu *et al.*, 1995]. However, a definite conclusion cannot be drawn.

Lindner *et al.* [1990] in SANS experiments studied a C14TASal solution in heavy water ( $D_2O$ ). The neutron scattering curve of a fresh unstressed solution could be fit by model calculations assuming homogeneous rigid cylindrical micelles. When the solution was stressed by cycling it for several hours in a turbulent flow, the friction and viscosity behavior changed. Furthermore, the shape of the scattering curve could no longer be fit by a single cylindrical model for the micelles. The change was most pronounced when the surfactant solution was stressed above the critical wall shear stress. The stressed solutions exhibited a significant increase in the mean radius of gyration. The new micellar form, once formed, did not change over several months when the surfactant solution was stored at rest at room temperature.

Schmidt *et al.* [1989] reported a decreasing active temperature range with time, i.e., the temperature interval in which drag reduction occurred was reduced with time. This effect could not be avoided when dissolved oxygen was present during the tests. When the tests were run in a nitrogen atmosphere and hydrazine was added as an oxygen scavenger no degradation occurred indicating that oxidation of the surfactant was the cause.

### 3.6 Diameter Effects

For Newtonian fluid turbulent flow, the Reynolds number includes the effect of pipe diameter, i.e., the turbulent flow of Newtonian fluids will follow a single friction factor-Reynolds number curve for different size pipes. However, for drag reducing fluids, this is not the case. The friction factor is a function of both  $N_{Re}$  and pipe diameter. Since most practical flow systems use larger pipe sizes than those in the laboratory, it is important to be able to scale up to predict drag reduction performance in large pipes from small diameter measurements. Some research has been done with polymer drag reduction scale-up. However, only a limited number of efforts have been made on surfactant drag reducers. These researchers tried to extend rules appropriate for drag reducing polymers to surfactants.

During his drag reduction study on a 508 ppm CTAB with equi-molar 1-naphthol system, White [1967] found drag reduction terminates at a fixed wall shear stress which was found to be independent of diameter. This was confirmed later by several researchers [Savins, 1969; Elson and Garside, 1983; Ohlendorf *et al.*, 1984; Rose *et al.*, 1984, 1989; Bewersdorff and Ohlendorf, 1988].

Hoyt [1991] developed a technique for scale-up of polymer drag reduction. He assumed that the negative roughness,  $\Delta B$ , is independent of diameter at a given friction velocity and the velocity profile for polymer drag reduction is shifted by  $\Delta B$  from that of Newtonian flow (see Eq. 20 and Fig. 3). The scaling process is relatively simple using this method and no iteration or graphical techniques are needed. This method is quite successful in pipe sizes larger than 10 mm. The reason for failure of the method for pipes smaller than 10 mm is believed to be the relatively stronger effect of the viscous sublayer in small tubes than in large tubes [Hoyt and Sellin, 1993].

Gasljevic and Matthys [1995] studied drag reduction of Ethoquad T/13-50 (2300 ppm) / NaSal (2000 ppm) solutions in four tubes of 2 mm, 10 mm, 20 mm and 52 mm. They found that with the exception of the 2 mm tube, drag reduction in the subcritical region (shear stress lower than critical shear stress) is a function of bulk fluid velocity and is independent of pipe diameter. The deviation is smaller than 7% over the pipe diameter range and velocity range of 0.5 to 10 m/s they studied. They also suggested that in the supercritical region (where drag reduction decreases with increase in velocity) the shear stress may be a better parameter.

Pollert *et al.* [1996] reported that drag reduction is increased with increasing pipe diameter for the 500 ppm Habon G system at diameters above 4 mm. They also investigated drag reduction in a 4 mm pipe in parallel with a 10 mm pipe as a simulation of a pipe network in real flow systems. They found that drag reduction in the 4 mm pipe of that network has a higher critical shear stress than that in a single 4 mm pipe. This held only if the diameter ratio of the parallel pipes was larger than 2.5:1. They were not able to explain this phenomenon. This might be related to the dependency of the

critical wall shear stress on the absolute pressure in the system [Povkh *et al.*, 1980].

Park *et al.* [1996] investigated drag reduction of CTAC/NaSal, STAC (stearyltrimethyl ammonium chloride) /NaSal and Habon G systems at low concentrations, 100, 250 and 500 ppm. They found that drag reduction increased with increasing concentration and with increasing pipe size (4.65 mm and 10.85 mm).

### 3.7 Heat Transfer Reduction in Drag Reducing Flows

Drag reduction is accompanied by a reduction in the heat transfer coefficient in tube-tube exchangers [White, 1970; Monti, 1972; Debrule and Sabersky, 1974; Dimant and Poreh, 1976; Rose *et al.*, 1984; Matthys, 1985, 1991; Christensen and Zakin, 1991]. It is believed that the increased thickness of the viscous boundary near the wall which accompanies drag reduction causes an increase in the thermal resistance between the wall and the bulk fluid and therefore a reduction in the rate of heat transfer [Sellin *et al.*, 1982a].

Rose *et al.* [1984] observed that viscoelastic surfactant solutions simultaneously lower the pipe flow friction and the heat transfer coefficient. However, since surfactants have a critical temperature and a critical shear stress at which drag reduction is lost and the heat transfer coefficients return to those of water, they suggested that heat exchangers should be designed to take advantage of this characteristic as a solution to the problem of the low heat transfer coefficients of drag reducing surfactant solutions.

Plate heat exchangers are very efficient in heat exchange. They rely on tortuous paths along parallel plates which lie close to each other. Christensen and Zakin [1991] investigated drag reduction and heat transfer reduction of the erucyltrimethylammonium/NaSal system both for a tube in tube heat exchanger and a plate heat exchanger. They measured heat transfer coefficient reduction in the latter from 10% to 65%, while the heat transfer coefficient reduction for a tube-tube heat exchanger was as high as 90% or more. They also observed a reduction in pressure loss across the plate

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exchanger as high as 50% at low flow rates and approaching 0% at high flow rates.

Similarly, Hammer and Sorensen [1995] reported 10 to 40% reduction of surfactant solution heat transfer coefficients in a plate exchanger compared to water. The reduction decreased with decrease in surfactant concentration and with increase in surfactant solution velocity. At moderate concentration and high velocity, the overall heat transfer coefficient was reduced by only 5%. Pressure drops across the exchanger were 10 to 18% lower than for water. Pollert *et al.* [1996] studied heat transfer to a drag reducing fluid (Ethoquad T/13-50/NaSal) in a plate heat exchanger. In their experiments, surfactant solution heat transfer coefficient reduction increased up to 55% with increases in surfactant concentration.

Thus, an additional benefit of the use of plate heat exchangers over tube-tube exchangers for drag reduction flow systems is that the solution side heat transfer coefficient reduction is smaller. Overall heat transfer coefficient reduction is, of course, also smaller. Suggested causes for the smaller decreases in heat transfer coefficient are the destruction of the secondary structure by a high shear region at the entrance to the plate exchanger or high shear stresses in the flow through the narrow and irregular channels of the plates. However, a simple calculation discloses that the average shear stress in the channels is much lower than the critical shear stress for loss of drag reduction although local stresses may be higher. Another possible reason is that the fluid flowing in the channels changes directions so often that the boundary layer is destroyed before it is fully developed, resulting in higher heat transfer coefficients compared with pipe flow [Christensen and Zakin, 1991].

For transport of heating or cooling water over long distances, the lower heat transfer coefficients are advantageous in reducing heat loss. For a liquid to air tube-tube heat exchanger, the air side resistance is dominant and the increased resistance of the drag reducing fluid is not a major effect. But for liquid-liquid tube-tube heat transfer the problem can be serious. Gasljevic [1995a] attempted to introduce a high shear obstacle at the entrance to the exchanger to temporarily destroy the micellar structure. Surprisingly in field

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tests at Völklingen, Germany [Kleuker *et al.*, 1991] and at Kladno-Krocehlavy, Czech Republic [Pollert *et al.*, 1994] no significant reductions in overall heat transfer coefficients were observed, possibly because the exchangers were old and corroded with high resistance in the corroded metal pipes or they were oversized.

### 3.8 Maximum Drag Reduction Asymptote

It has been found that for polymer drag reduction, there is a maximum asymptote [Castro and Squire, 1967; Giles and Pettit, 1967; Virk *et al.*, 1970; Virk, 1975]. There are several different forms of the asymptote. That proposed by Virk is widely acknowledged as valid for high polymer drag reduction:

$$f^{-\frac{1}{2}} = 19.0 \log(N_{Re} f^{\frac{1}{2}}) - 32.4 \quad (9)$$

or:

$$f = 0.58 N_{Re}^{-0.58} \quad (N_{Re} = 4,000 - 40,000) \quad (10)$$

Thus drag reduction flow data for polymer solutions usually lie between the von Kármán line and Virk's asymptote. For surfactant drag reducers, however, the friction factor may be lower than that predicted by Virk's asymptote [McMillan *et al.*, 1970, 1971; Hershey *et al.*, 1975; Lee *et al.*, 1974; Sylvester and Smith, 1979; Bewersdorff and Thiel, 1993; Chara *et al.*, 1993]. Based on data for cationic surfactants in water and aluminum disoaps in hydrocarbons, Zakin *et al.* [1996] proposed a new asymptote for non-polymeric drag reducers:

$$f = 0.32 N_{Re}^{-0.55} \quad (11)$$

This asymptote expressed friction factor as an explicit function of Reynolds number and is easy to plot. It can be seen that the new asymptote

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predicts friction factors which are significantly lower than those predicted by Eq. 9 (Fig. 2).

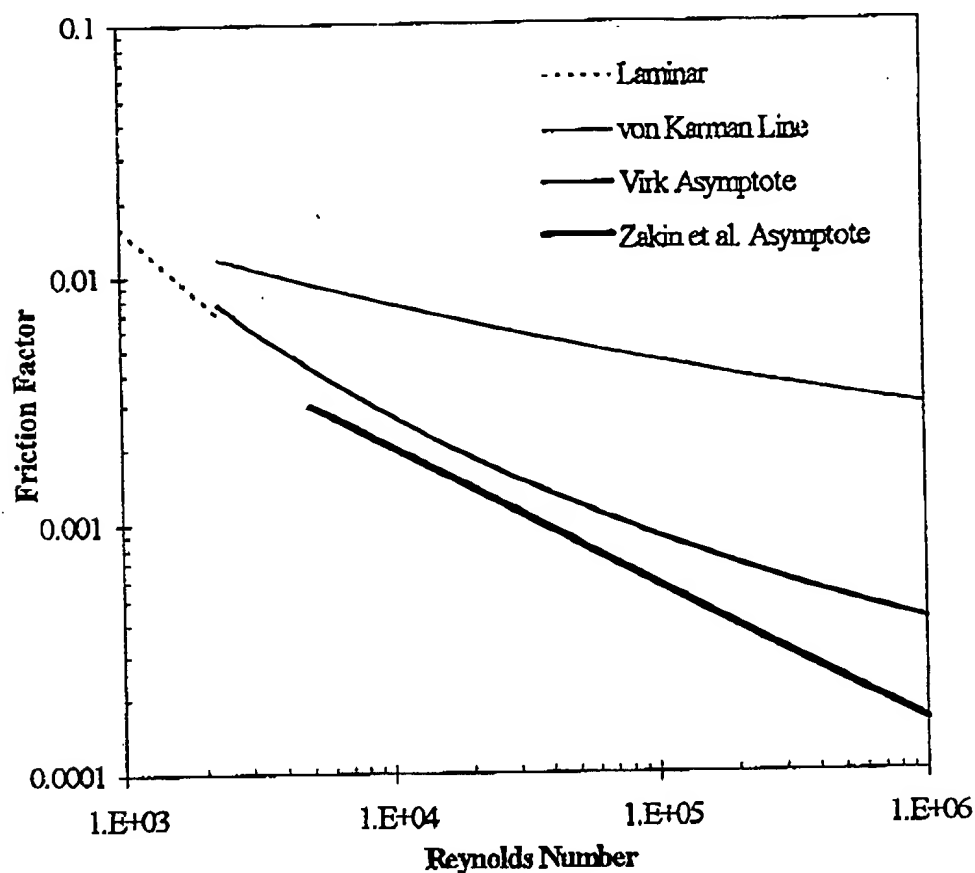


Fig. 2: Newtonian friction factors and drag reduction asymptotes [Lu, 1997c].

### 3.9 Investigations on Mechanism of Surfactant Drag Reduction

Even though more than half of a century has elapsed since the first report of drag reduction, the mechanism for drag reduction is still unknown. Several hypotheses have been proposed but none of them discloses the detailed mechanism for drag reduction. Efforts have been made in surfactant drag reduction research to clarify the mechanism by several characterization methods, including turbulence measurements, rheology measurements, and small angle light scattering measurements, some of which will be described below. However, in many rheological studies, surfactant solutions of higher

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concentration than those used in drag reduction were used for characterization. The results of these studies may not be suitable to characterize drag reduction surfactant solutions rheologically. We will only include results on solutions with concentrations in the range suitable for drag reduction applications.

#### 3.9.1 Velocity Profiles of Surfactant Drag Reduction Flow

##### 3.9.1.1 Turbulent Flow Velocity Profiles for Newtonian Fluids

The turbulent flow velocity profile for Newtonian fluids is arbitrarily divided into three regions: the viscous sublayer, the buffer layer and the turbulent core. The three regions are described by the following equations:

1. Viscous sublayer ( $0 < y^+ < 5$ ):

$$u^+ = y^+ \quad (12)$$

2. Buffer layer ( $5 < y^+ < 30$ ):

$$u^+ = 5.0 \ln y^+ - 3.05 \quad (13)$$

3. Core ( $y^+ > 30$ ):

$$u^+ = 2.5 \ln y^+ + 5.5 \quad (14)$$

The dimensionless  $u^+$  and  $y^+$  are defined as:

$$u^+ = \frac{u}{U^*} \quad (15)$$

$$y^+ = \frac{U^* y}{\nu} \quad (16)$$

where  $u$  is the time averaged local mean velocity,  $y$  is the distance from the wall,  $\nu$  is the kinematic viscosity of the fluid and  $U^*$  is the shear velocity defined by:

$$U^* = \sqrt{\frac{\tau_w}{\rho}} \quad (17)$$



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### 3.9.1.2 Turbulent Flow Velocity Profiles for Drag Reducing Fluids

Based on the maximum drag reduction asymptote for high polymers, Virk [1971] proposed a three-zone model for the mean velocity profile of drag reducing polymer solutions:

1. Viscous sublayer ( $0 < y^+ < 11.6$ ):

$$u^+ = y^+ \quad (18)$$

2. Elastic sublayer ( $11.6 < y^+ < y_e^+$ ):

$$u^+ = 11.7 \ln y^+ - 17.0 \quad (19)$$

This equation, often called Virk's ultimate velocity profile, predicts the steepest profile observed for high polymer systems.

3. Core ( $y^+ > y_e^+$ ):

$$u^+ = 2.5 \ln y^+ + 5.5 + \Delta B \quad (20)$$

where  $\Delta B$  is an effective shift from the Newtonian profile. The value of  $y_e^+$  is a function of  $\Delta B$  as determined by Eqs. (16) and (17):

$$y_e^+ = \exp\left(\frac{\Delta B + 22.5}{9.2}\right) \quad (21)$$

The friction factor for drag reducing flows of polymer solutions is [Virk, 1971]:

$$f^{-\frac{1}{2}} = 4.0 \log(\text{Re } f^{\frac{1}{2}}) - 0.4 + \frac{\Delta B}{\sqrt{2}} \quad (22)$$

which is similar in form to the von Kármán equation (see Eq. 8).

Results of turbulent mean velocity profile and structure of turbulence measurements for surfactants are reported in both channel [Povkh *et al.*, 1975, 1980, 1988; Gyr and Bewersdorff, 1995; Kawaguchi *et al.*, 1996; Schmidt, 1997] and pipe flows [Bewersdorff and Ohlendorf, 1988; Bewersdorff, 1990; Chara *et al.*, 1993; Bewersdorff and Thiel, 1993; Myska *et al.*, 1995; Kawaguchi *et al.*, 1996; Park *et al.*, 1996]. In general, the

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viscous sublayer seems to be unchanged in comparison to a Newtonian fluid; there is an increase in slope in the intermediate region and a velocity shift upwards with no increase in slope in the region near the centerline (see Fig. 3). There is a relationship between the shape of the dimensionless mean velocity profile in the intermediate region and the magnitude of drag reduction. At low levels of drag reduction the surfactant velocity profiles look similar to those found in drag reducing polymer solutions [Povkh *et al.*, 1980; Bewersdorff and Ohlendorf, 1988], i.e., these profiles can be described by Virk's [1971] model. At higher levels of drag reduction, the velocity profiles follow Virk's ultimate profile, Eq. (19) in the elastic sublayer exhibiting a large increase in slope in this region compared to the Newtonian solvent [Povkh *et al.*, 1980; Bewersdorff and Ohlendorf, 1988; Bewersdorff, 1990].

However, when the friction factor for the surfactant solution becomes close to or is lower than Virk's maximum drag reduction asymptote, Eq. (9), deviations from Virk's ultimate profile, Eq. (19), occur. These profiles deviate from Eq. (19) giving lower dimensionless velocity values at smaller wall distance, higher ones in the medium range, and again lower ones at larger wall distances. These S-shaped velocity profiles were detected by Povkh *et al.* [1980], Bewersdorff and Ohlendorf [1988], Bewersdorff [1990] and Chara *et al.* [1993]. For  $y^+ > 30$  the velocity profiles can be approached by a logarithmic profile, similar to Eq. (19), however, with an increased slope.

Chara *et al.* [1993] performed LDA measurements on mean velocity and turbulence intensities of a Habon G surfactant solution in a 39.4 mm diameter pipe. For solutions approaching the non-polymeric friction factor asymptote, they found that the limiting elastic sublayer mean velocity profile is:

$$U^+ = 23.4 \ln y^+ - 65 \quad (23)$$

The slope, 23.4, is close to 19.5 which was reported by Bewersdorff and Thiel [1993] for a strongly drag reducing surfactant solution and both are

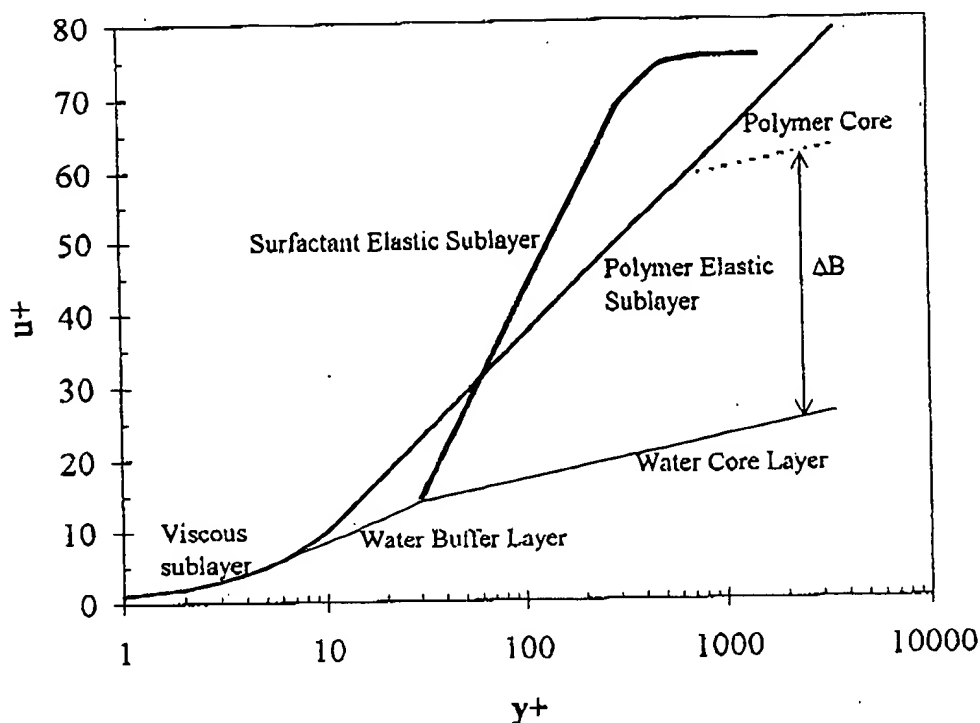


Fig. 3: Turbulent mean velocity profile for drag reducing polymer and surfactant solutions

steeper than the profile proposed by Virk in Eq. 19 (see Fig. 3). Chara *et al.* [1993] also found that in the core region the mean velocity profiles observed for drag reducing surfactant systems are flatter than most of those reported for polymer solutions.

Axial velocity fluctuations for surfactant systems are lower than water in most of the outer region, approach those of water at the center of the tube but are higher near the wall. Tangential and radial turbulence intensities for surfactant drag reduction flows are reduced to 20% to 35% of those for water at all locations in the tube [Chara *et al.*, 1993; Myska *et al.*, 1996]. Chara *et al.* [1993] also reported that the ratio of radial velocity fluctuation,  $u_r'$ , to axial velocity fluctuation,  $u_z'$ , is about 0.6, which is larger than 0.39 to 0.47 reported by Bewersdorff [1990] for surfactant solutions. Reductions in radial velocity fluctuations were also observed by Kawaguchi *et al.* [1996], Park *et al.* [1996] and Schmidt [1997].

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Turbulent energy spectra of surfactant drag reducing solution are similar to those of polymer drag reducing solutions. That is the power spectra are shifted to lower frequencies compared with water and the high frequency components are attenuated [Myska *et al.*, 1995].

From the auto-correlation function of the axial velocity fluctuations the micro and the integral scale of turbulence can be calculated. These turbulent time scales provide information on the size of the smallest and the largest eddies in the flow. In a drag reduced flow of a C14TASal solution, Bewersdorff and Ohlendorf [1988] found both scales to be increased over the whole cross-section of the pipe in comparison to a Newtonian solvent and, of course, length scales increased. The largest increase of the length microscale occurred in the near-wall region. Increased microscale in turbulent flows of surfactant solutions can be interpreted as an increase in size of the small eddies in the dissipation range. This can be caused by a locally increased viscosity. The increase of the integral scale shows that the large scale structure of turbulence is also affected. A change of the large scale structure in flows of drag reducing C14TASal solutions also was observed in a mixing layer by Riediger [1987, 1989]. In the same experiments, however, a drag reducing polyacrylamide polymer solution showed no change in the large scale structure, but the size of the smallest eddies in the dissipation range increased.

By analyzing the higher moments of turbulence in a channel flow of a solution of the surfactant "Methaupon," Povkh *et al* [1988] found that the zero-crossing of the skewness and the minimum of the flatness were shifted to higher dimensionless wall distances in comparison to a Newtonian fluid. Thus the region of maximum turbulent energy production also occurs at larger distances from the wall. Furthermore, Povkh *et al.* [1988] found that in the zone of maximum energy production a larger percentage of the fluctuations is weak and the number of strong fluctuations is smaller than in Newtonian turbulence.

An interesting finding in Kawaguchi *et al.*'s [1996] study is that the Reynolds stresses in a drag reducing flow of a 50 ppm CTAC/50 ppm NaSal surfactant solution are essentially zero, significantly lower than those of

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water. Schmidt [1997] reported a similar result with an Ethoquad T/13-50/NaSal solution in a channel. Strong reduction of the Reynolds stresses also was observed in channel flow of drag reducing surfactant solutions by Povkh *et al.* [1988], Gyr and Bewersdorff [1995], and Massah and Hanratty [1996] and in pipe flows by Bewersdorff [1990]. Stress balances showed that there were significant stress deficiencies, that is in these flows the total stress is larger than the sum of the viscous and the Reynolds stresses at all locations even when the viscous shear stresses were calculated using the solution viscosity. The observed stress deficits strongly depended on the wall distance. Several similar observations of stress deficiencies for polymer drag reduction flows were observed earlier. Bewersdorff [1984] found that the total shear stress was not equal to the sum of a Reynolds stress and a viscous shear stress for a polymer solution. Willmarth *et al.* [1987] observed a similar effect in a 10 ppm POLYOX solution.

Massah and Hanratty [1996] used a FENE bead-spring model to numerically simulate turbulent flow in a channel. Their simulation is able to produce a so-called "added stress" for polymer drag reducers. This might compensate for the observed stress deficiencies. Another possible rheological explanation for the observed stress deficit could be a locally increased "effective" viscosity, as suggested by Giesekus [1981] and Bewersdorff and Berman [1988]. Some drag reducing surfactant solutions are shear thickening, i.e., in a certain shear rate range their shear viscosity increases significantly (see following section on rheology).

Kawaguchi *et al.* [1996] also investigated the effect of wall heating on surfactant drag reduction flow. They found that when a flush mounted wall heating element was activated, the mean velocity profile near the wall approached that of a turbulent Newtonian fluid. Also,  $u'$  and  $v'$ , and the Reynolds stress increased near the heated wall. Based on their results, they suggested the possibility of controlling drag reducing flow through heating. Stuer and Gyr [1996] compared turbulent velocity profiles of polymer drag reduction flows with surfactant drag reduction flows. In contrast with the results of Kawaguchi *et al.* [1996], they concluded that high polymers act primarily in the near wall zone while surfactants act in the core of the flow.

LDV measurements show major differences between drag reducing and ordinary fluids. The differences in turbulence intensity in all three directions, the extreme of very small or zero Reynolds stresses and the shift of power spectrum to lower frequencies are important findings. Small-angle-neutron scattering (SANS) experiments of Bewersdorff *et al.* [1986] in a turbulent channel flow and of Bewersdorff *et al.* [1989] and Lindner *et al.* [1990] in turbulent pipe flow of a C14TASal solution in heavy water ( $D_2O$ ) showed that no anisotropy in the scattering pattern existed below the onset of drag reduction, which means that the micelles rotate in the shear flow and thus they are statistically oriented. After the onset of drag reduction the anisotropy of the scattering pattern correlated with drag reduction, and when the friction factor approached Virk's maximum drag reduction asymptote, Eq. (9), a nearly complete alignment of the rod-like micelles in the flow direction was detected from the scattering pattern. These SANS experiments confirmed the early results obtained by magnetic birefringence [Porte *et al.*, 1980] and flow birefringence [Wunderlich *et al.* 1987] measurements indicating that the micelles are oriented with their long axis parallel or nearly parallel to the flow direction in laminar Couette flow as well as in turbulent drag reduced pipe and channel flows when a critical shear stress is exceeded. The loss of drag reduction above the (second) critical wall shear stress was accompanied by vanishing of the orientation of the micelles. The micelles are not destroyed, but they are disaligned and rotate in the turbulent shear flow.

The mechanism causing these phenomena has to be an interaction of the turbulence with the non-Newtonian fluid properties of the viscoelastic surfactant solutions. Thus the rheology of these solutions plays an important role and will be reviewed.

### 3.9.2 Rheology

Drag reducing surfactant solutions are usually very dilute. Their concentrations are generally less than 0.5% and often quite a bit lower. However, most of these solutions are extremely non-Newtonian and rheological measurements are very important in order to determine which, if any, relationships exist between non-Newtonian behavior and drag reduction effectiveness.

### 3.9.2.1 Shear Viscosity

Ekwall *et al.* [1971] measured the viscosity of 0.036% (CMC<sub>1</sub>) up to 26% CTAB solutions without additives. They found that the reduced viscosity increased with concentration. At concentrations between 9% and 11%, the curve had a change in slope where they believed the spherical micelles changed to rod-like micelles. At a concentration of 26%, a narrow two phase region appears where the micellar aqueous solution is in equilibrium with the mesomorphous middle soap [Ekwall *et al.*, 1971].

With the presence of salts, the viscosities of the surfactant solutions are quite different from those without salt. It has been shown that the addition of salts to anionic and nonionic surfactants can change surfactant viscosity dramatically. Pilpel [1966] found that when the concentration of KCl increased from 0.6 (4.47%) to 1.2M (8.94%) in a 0.035M (1.12%) potassium oleate solution, the solution viscosity increased from 10 to 70 poises, and then the solution viscosity decreased with further addition of salt. The potassium oleate concentration is about five times the concentration at which Savins [1967] studied drag reduction of this anionic system, however. Chang and Zakin [1985] also found a large effect of salt addition in a nonionic system. On the other hand, for a cationic system, Stainsby and Alexander [1953] reported that there is only a small viscosity increase compared with that of water for a 0.44 M cetylpyridinium chloride with 1.0 M NaCl solution. Thus, the effect of the added salts depends on the surfactant, the salts and the concentration range.

The effect of organic additives on the viscosity is even more significant. Stainsby and Alexander [1953] found that in the presence of NaCl, the CPyCl solution viscosity increases sharply with increasing concentration of chlorobenzene to a peak and then decreases sharply. The peak viscosity of the solution can be thousands of times greater than that of the solution without chlorobenzene. Rehage and Hoffmann [1991] also observed a similar peak for a CPyCl solution with sodium 4-methyl benzoate as counterion. Wan [1968] studied the effect of salicylate on the viscosity of various cationic surfactants. She found the viscosity increases with increasing salicylate to a peak and then decreases. Larsen *et al.* [1973] studied the effect of organic

additives on the viscosity of a 0.1 M CTAB/0.1 M NaBr solution. They found that additives such as benzene, n-hexanol, benzoic acid, chloroform and methylene chloride can increase the solution viscosity up to two orders of magnitude. They also noted that while both ethanol and hexane have little or no effect, n-hexanol causes a great change. However, in the absence of NaBr in the solution, all these organic additives have only small effects on the viscosity.

These dramatic viscosity changes are believed to be caused by changes in the micellar structure. Doi and Edwards [1978a, b] established an equation for the viscosity of a dilute rod-like micellar solution:

$$\eta_0 = \eta_s(1 + \hat{c}L^3) \quad (24)$$

where  $\eta_0$  is the viscosity of the solution at zero shear rate,  $\eta_s$  is the viscosity of the pure solvent,  $\hat{c}$  is the number of rods per unit volume and  $L$  is the length of rods. The  $\hat{c}$  can be calculated by a simple equation:

$$\hat{c} = \frac{c_M M}{\pi p r^2 L} \quad (25)$$

where  $c_M$  is the surfactant concentration,  $M$  is the molecular weight of the surfactant monomers,  $r$  is the short radius of the rod-like micelles and  $\rho$  is the density of the solution. Substitution of Eq. (25) into Eq. (24) leads to:

$$\eta_0 = \eta_s(1 + KL^2) \quad (26)$$

where  $K = c_M M / \pi p r^2$ . This equation is only valid for dilute solutions according to Doi and Edwards [1978b]. From this equation, it can be seen that the viscosity increases with the square of the rod-like micelle length. The addition of salts promotes the growth of rod-like micelles and results in the rapid increase in the viscosity.

Interference arises when the rotational volumes of the rods actually touch one another or even more when the rods begin to overlap. The condition for overlapping rods is



$$\hat{c} \gg 1/L^3 \quad (27)$$

For concentrated solutions, i.e., when Eq. (27) is satisfied, Doi and Edwards [1978a, b] proposed a different equation for the viscosity

$$\eta_0 = \eta_s [1 + (\hat{c}L^3)^3] \quad (28)$$

By substitution of Eq. (25) into Eq. (28):

$$\eta_0 = \eta_s (1 + K^3 L^6) \quad (29)$$

Thus for concentrated solutions or solutions with long rods, viscosity increases very rapidly with the rod length. At higher concentrations the micelles can form three-dimensional networks, in which the substructure micelles can still be recognized.

### 3.9.2.2 Viscoelasticity

Though viscosity changes with shear and additives, shear viscosity at high shear rates ( $>1000 \text{ s}^{-1}$ ) of drag reducing surfactant solutions is relatively constant, about two to five times that of water. Obviously, drag reduction is not caused by the slightly higher shear viscosity. On the other hand, many authors who studied drag reducing surfactant systems [Savins, 1967; Gravsholt, 1976; Elson and Garside 1983; Ohlendorf *et al.*, 1984, 1986a, b; Rose *et al.*, 1984, 1989; Rehage *et al.*, 1986; Bewersdorff and Ohlendorf, 1988; Chou, 1991b; Bewersdorff and Thiel, 1993; Stern *et al.*, 1994; Gyr and Bewersdorff, 1995; Lu *et al.*, 1996a, b, d] have stated that viscoelastic rheological properties of the surfactant solutions are responsible for the occurrence of drag reduction.

Viscoelasticity is often observed in biological and macromolecular systems, and it can also be observed in dilute drag reducing polymer and surfactant systems. For surfactant drag reduction, Savins [1967] was the first to recognize that drag reducing surfactant solutions show viscoelastic flow behavior.

Gravsholt [1976] found that dilute aqueous CTA-X systems, where X is a substituted benzoic acid, are viscoelastic. Viscoelasticity in surfactant systems can be induced by the addition of three different types of added molecules: a second, oppositely charged surfactant, organic counterions and some uncharged compounds like esters or aromatic hydrocarbons [Rehage and Hoffmann, 1991], in addition to the compounds reported by Larsen *et al.* [1973] described above. Hoffmann and Rehage [1987] claimed that most of the viscoelastic surfactant systems are cationic surfactants having a cetylpyridium or a trimethylammonium head group with different anionic counterions. Later investigations showed that hydroxyethyl groups substituted for the methyl groups give similar behavior.

The viscoelasticity can be simply characterized by the swirl decay time (SDT) which was proposed and used by Nash [1956a, b]. He set up a swirling motion in a fixed volume of solution in a flask and noted the time between the stopping of the vessel rotation and the cessation of the solution movement before recoil, which he defined as SDT. The smaller the SDT is, the greater the viscoelasticity of the solution. Elson and Garside [1983] measured the SDT of CTAB/1-naphthol solutions against the relative amount of 1-naphthol and the temperature. One of their important observations was that the critical wall shear stress at which drag reduction is lost reaches a maximum when the solution has a minimum swirl decay time (SDT) or maximum viscoelasticity. This result relates solution viscoelasticity to drag reduction. Lu *et al.* [1996b] showed that the SDT decreases with increasing counterion to surfactant ratio when it is smaller than unity.

The first normal stress difference,  $N_1$ , is another characteristic of viscoelasticity. Hu and Matthys [1995] reported  $N_1$  values over 300 Pa for 5 mM Ethoquad T/13-50 with 5 mM NaSal solutions. They also found that the relaxation of  $N_1$  can be fit by a double exponential function. Myska *et al.* [1996] showed high  $N_1$  values for C18TSal solutions at temperatures higher than 30°C, but also observed zero  $N_1$  at 20°C where the solution is drag reducing. Lu *et al.* [1996a] observed that the viscoelasticity, as characterized by  $N_1$ , is dependent on the chemical structure of the counterion, as is drag reduction.  $N_1$  also increases with surfactant concentration [Lu *et al.*, 1996d] and counterion to surfactant ratio [Lu *et al.*, 1996b].

It is generally agreed that strong elastic forces arise from interaction between elongated, rod-like micelles [Elson and Garside, 1983; Rehage and Hoffmann, 1991]. Hoffmann *et al.* [1984b] observed that the viscosity and the viscoelasticity of surfactant solutions rise abruptly when the length of the rod-like micelles exceeds their mean separation distance. They believed that these rheological properties are caused by a 3-D dynamic network which is formed as soon as the length exceeds the mean distance. Ulmius *et al.* [1979] proposed that a long-range periodic structure is responsible for the viscoelasticity in the solutions.

—Shikata *et al.* [1987] classified the viscoelasticity of CTASal solutions into three types. Type I and Type II are for low and intermediate ratios of counterion to surfactant, respectively. Type III is for a high concentration ratio. Type I behaviors are similar to the features observed for unentangled flexible-chain polymer systems. Beginning at Type II, surfactant solutions behave like polymer systems with entanglement, which means the formation of an entanglement network. Type III can be represented by the Maxwell model. They further suggested that the relaxation time is affected by the free salicylate concentration and the free salicylate molecules behave like a catalyst for a disentangling reaction [Shikata *et al.*, 1988; 1991].

However, Lu *et al.* [1997a, c] reported an effective drag reducing surfactant system which lacks normal viscoelasticity characteristics: the solution has zero  $N_1$  values and it shows no overshoot and no recoil. It did, however, exhibit high apparent extensional viscosity [Lu *et al.*, 1997a, c]. Thus, the correlation between drag reduction and viscoelasticity is questionable. In a later section, we will review measurements of extensional viscosity.

### 3.9.2.3 Network and Shear Induced Structure (SIS)

The fact that some surfactants can be effective drag reducing additives and may increase in viscosity under shear suggested to some researchers that some kind of network structure exists or is formed under shear in surfactant solutions, equivalent to networks formed in polymer solutions. As early as

1954, based on both hydrophobic and electrostatic energy considerations, Pilpel [1954] developed a model to explain the formation of gels. He concluded that gel formation is caused by the conversion of spherical micelles into long, interlinked cylindrical micelles. He believed that the viscoelastic properties develop as a result of the interlinking and suggested that this network structure is similar to the one that exists in elastic solids such as rubber, gelatin, and plastic materials.

The evidence from dynamic viscoelastic measurements [Hoffmann *et al.*, 1984a, b; Shikata *et al.*, 1987; Wunderlich *et al.*, 1987; Strivens, 1989; Shikata and Kotaka, 1991] suggests that a fully entangled network exists. Strivens [1989] studied the CTAB-SA (salicylic acid) system at concentrations of 0.1, 0.01 and 0.001 M. He found that no viscoelasticity was detectable in the 0.001 M solution. The viscosity and stress relaxation data for the 0.1 M solution were found to be well-described by a Maxwell model, but not for the 0.01 M and 0.001 M solutions. The storage modulus ( $G'$ ) and loss modulus ( $G''$ ) curves for the 0.01 M and 0.1 M solutions cross each other, and  $G'$  reaches a plateau value for the 0.1 M solution. Similar results were obtained by Shikata *et al.* [1987] when they studied the CTAB/NaSal system. They kept the concentration of CTAB at 0.1 M and changed the amount of NaSal to vary the ratio of NaSal to CTAB. They found that above a ratio of 0.275, the  $G'$  and  $G''$  plots cross each other, and the cross point moves to a higher frequency with increase in ratio. When the ratio reaches 0.5,  $G'$  reaches a plateau and the plateau value doesn't change with further addition of NaSal. Since the plateau is a consequence of cross-links between the aggregates [Hoffmann *et al.*, 1984b], they concluded that a fully entangled network is already formed when the molar ratio of NaSal/CTAB reaches 0.5. This indicates that at high angular frequencies the solution behaves as an elastic body.

Hoffmann *et al.* [1985a] suggested that the rod-like micelles can be held together in bundle-like structures by adhesion forces which are strong enough to overcome the electrostatic repulsion between the micelles. They suggested that these adhesion forces are due to van der Waals forces or to the interfacial tension between the rods and the aqueous phase.

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As mentioned in Section 2.2, network structure has been observed in surfactant systems by using cryo-transmission electron microscopy (cryo-TEM) [Bellare *et al.*, 1988; Vinson and Talmon, 1989; Walter *et al.*, 1991; Clausen *et al.*, 1992; Cochlin *et al.*, 1992; Lu *et al.*, 1996a, b, c, d, 1997a, c; 1998]. In preparing samples for cryo-TEM, significant shear is applied. Thus, the network structure observed may be induced by shear.

Several researchers have suggested that such network structures may be induced by shear. Ohlendorf *et al.* [1986a] performed rheological studies on 1000 ppm C14TASal and 1000 ppm C16TASal solutions (CTAB or CTAC plus equimolar NaSal). The rod-like micelles in their solutions were believed to have an average length of 15 to 40 nm and a diameter of 4 nm, giving an average separation between them larger than 50 nm. For their solution,  $\hat{c}$  is less than  $1/L^3$ , i.e., the condition for overlapping rods in Eq. (27) is not satisfied and therefore, these rod-like micelles should have no interaction with each other. Based on this, the individual micelles should not be able to affect the flow up to a high shear rate. However, they found the viscosity measured in a Couette flow cell is slit width dependent, a result confirmed by Wunderlich and Brunn [1989] for concentric cylinder measurements and by Hu and Matthys [1995] for parallel plate and conical-cylinder measurements. Furthermore, in measuring the shear viscosities of the solutions, they found that at some shear rate between 10 to 100  $s^{-1}$ , the viscosity of the system increased abruptly. This phenomenon was also reported in many other papers [for example, Ohlendorf *et al.*, 1986b; Rehage *et al.*, 1986; Bewersdorff and Ohlendorf, 1988; Wunderlich and Brunn, 1989; Lindner *et al.*, 1990; Bewersdorff, 1989, 1996; Hu and Matthys, 1995]. These researchers observed that the viscosity was usually very low at low shear rates and then at a critical shear rate, viscosity suddenly increased to high values; in some cases the increase was 8 times. Their viscosity jumps depended on concentration, temperature, geometry of the viscometer, gap width and shear rate. The critical shear rate where the jump occurred increased with surfactant concentration, counterion/surfactant mole ratio and with temperature and the jump was only observed at low temperature. The solutions were always shear thinning after the jump. Ohlendorf *et al.* [1986a] suggested that the increase

in viscosity was induced by an abrupt change in the microstructure of the surfactant solutions.

However, data from other studies do not show any viscosity jump. Rose and Foster [1989] measured the viscosity of 0.2 % CTASal + 0.2% NaSal solution (molar ratio of counterion to surfactant is about 3.7). They found the viscosity at room temperature decreases with increasing shear rate from  $1 \text{ s}^{-1}$  up to  $500 \text{ s}^{-1}$ , i.e., the solution exhibits shear thinning behavior. Earlier measurements on CTAB/1-naphthol solutions by Elson and Garside [1983] gave shear thinning behavior at low shear rates (below  $300 \text{ s}^{-1}$ ) and constant viscosity at high shear rate. Myska *et al.* [1996] also only observed shear thinning for a C18TAC solution at 1.6 and 5 mM concentrations with 2.5 times (molar) of NaSal. These shear thinning observations support the concept of alignment of the rod-like micelles as shear increases. Lindner *et al.* [1990] showed that the viscosity jump observed by Ohlendorf *et al.* [1986a] can vanish in solutions stressed above the critical shear stress. After subjecting the solution to turbulent flow for several hours above the critical wall shear stress (stressed solution), the viscosity was lower than that of the fresh solution, and no viscosity jump was observed. No explanation was offered for this change in behavior. From their small angle neutron scattering measurements, they concluded that the rod-like micelles are broken up by the forces in the turbulent flow field and form smaller micelles which build up loose but lasting superstructures which are stable with shear and have constant but lower viscosity.

The discrepancy between the two different observations regarding the viscosity jump may be explained by observations made by Shikata *et al.* [1987], Hoffmann and Rehage [1987] and Hu and Matthys [1996]. As mentioned above, Shikata *et al.* [1987] classified the viscoelasticity of CTAC solutions into three types in terms of the ratio of NaSal to surfactant. Type II and Type III with intermediate and high NaSal concentration behave like entangled polymer solutions while Type I with low NaSal concentration behaves like unentangled flexible-chain polymer systems. Hoffmann and Rehage [1987] classified viscoelastic surfactant solutions into two types. In the first and more general type, the structures causing viscoelastic behavior

are present in the stagnant solution, which is the same as Type II and Type III of Shikata *et al.* [1987]. In the second type, viscoelasticity is observed only after a certain threshold shear rate is exceeded, which is similar to Type I of Shikata *et al.* [1987]. Systems of the second type are called shear induced viscoelastic systems. Recently, Hu and Matthys [1996] suggested an identical classification. For surfactant solutions in which networks already exist, no shear is needed to induce a superstructure and no viscosity jump is apparent. This explanation is reasonable if one notes that the systems with viscosity jump have a 1:1 or lower counterion/surfactant ratio and higher ratios give no jumping.

Rehage *et al.* [1986] found that both the first normal stress difference and flow birefringence do not show up in the first ten seconds of shearing, and then they both jump to a steady state level. The first normal stress difference,  $N_1$ , is another characteristic of viscoelasticity. Hu and Matthys [1995] observed similar shear stress and first normal stress difference behaviors, i.e., low or zero stress values in the first tens of seconds for a 5 mM Ethoquad T/13-50 (tallow tris-hydroxyethyl ammonium acetate) with 5 mM NaSal solution followed by a rapid increase to the plateau value.

According to its proposers, the SIS only exists in certain shear rate ranges [Ohlendorf *et al.*, 1984; Hoffmann *et al.*, 1985a; Ohlendorf *et al.*, 1986a; Rehage *et al.*, 1986]. The SIS is formed after the shear rate exceeds a well defined threshold value which is defined by concentrations and ratios, while at very high shear rates, the SIS is no longer stable. As noted earlier, Lindner *et al.* [1990] proposed a loose but long lasting (several months) superstructure for surfactant solutions after experiencing turbulent flow above the critical wall shear stress. Wunderlich *et al.* [1987] found the shear induced structure in laminar flow gave an extinction angle close to zero in their flow birefringence measurements on TTASal solutions. They believed the SIS consists of small clusters of rod-like micelles and can be formed only when the shear rate exceeds a certain threshold value, as shown by their kinetic model. They claimed that the product of the relaxation time of the SIS and the critical shear rate, at which the SIS forms, is a constant of the order of 100, but didn't show how they measured the relaxation time of the SIS. The decay of the SIS is believed to be a multistep process as also shown by

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Shikata *et al.* [1988], Hu and Matthys [1995] and Lu *et al.* [1997a].

Two spatial arrangements of the rod-like micelles in the SIS were proposed by Ohlendorf *et al.* [1986a]: a) Build-up of a pseudo-lattice from the rods with lattice planes sliding past each other and in which the rod-like micelles are preferentially aligned in the flow direction. b) A pearl-string model in which aligned rods are held together by attractive forces like pearls on a string and with the strings oriented in the direction of the flow parallel to one another. Bewersdorff and Ohlendorf [1988] proposed two different models for the structure of SIS: coalescence of the rod-like micelles to form very long flexible rods that act like high molecular weight polymers, or the build-up of ordered structures of individual rods by cooperative electrostatic interaction. However, there are still no direct experimental observations to support these models of shear induced structure.

Cates and coworkers (for example, Turner and Cates, 1991; Turner *et al.*, 1996) and a number of other investigators have done theoretical studies of the dynamics of self-assembling long rodlike or wormlike micelles. They proposed that the chains of these self-assembled micelles form "effective" networks. These so-called "living polymers" are subject to reversible scission and recombination which leads to different relaxation behavior than reptating polymer chains. The continuous breaking and repair of the micellar chains provides an additional form of stress relaxation. That is, stress relaxation in micellar networks occurs through an interplay of the reptation and the breaking processes. For rapid scission kinetics, linear viscoelastic (Maxwell) behavior is predicted and is observed for some surfactant systems at low frequencies. In some cationic surfactant systems, however, the observed behavior in Cole-Cole plots does not fit the Maxwell model (Lu, 1997c).

Koch (1997) points out predictive deficiencies in many of the previous hypotheses and mathematical models proposed for explaining the formation of shear induced states in dilute cationic surfactant solutions. He offered a model which takes into account shear effects on single micelles utilizing a thermodynamic model (Israelachvili *et al.*, 1976 and Tanford, 1980). Hydrodynamic forces were calculated using a rigid-dumbbell model. While



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his model does not give explicit information on the shear induced state, he claimed that its predictions are in better qualitative agreement with experiments on freely rotating micelles in cationic surfactant solutions below the overlap concentration than the models of previous authors.

In a viscometer the surfactant solutions exhibit time dependent flow behavior in the shear induced state, i.e., the torque varies with time and thus the reported viscosity and shear stress data are time averaged. Recently, Spenley *et al.* [1996] and Keller *et al.* [1998] attributed this flow phenomenon to a flow instability involving the formation of shear bands, i.e., there are layers coexisting in which the shear rate is very different. One layer behaves nearly like a low viscous Newtonian fluid, whereas the other layer contains a highly viscous and viscoelastic nematic surfactant phase.

To study shear induced phase transitions, Boltenhagen *et al.* [1997a, b] used a light scattering microscopy technique to observe structural changes of equimolar cationic surfactant-counterion systems under shear in a Couette Cell. Their results indicate that a dynamic phase transition occurs above a critical shear rate in the gap coincident with a discontinuity in the shear stress and rapid increase in apparent viscosity.

In constant shear rate experiments above the critical shear rate, they found that the shear induced phase fills the gap after sufficient time has elapsed. However, in constant shear stress experiments at stress levels just above that corresponding to the stress value just before the discontinuity found in the constant shear rate experiment they observed coexistence of two phases separated by a single stable interface. The position of this interface in the gap depended on the stress level. They explained the constant shear rate results in terms of a feedback mechanism as the initial appearance of the more viscous phase caused an increase in stress causing growth of the phase and still higher stress, etc. In contrast, the constant shear stress feedback mechanism stabilizes the system as it leads to lower shear rates, and stable coexisting phases are possible.

In the constant stress experiments of Boltenhagen *et al.* [1997b], steady state shear stress vs. shear rate data show that in the critical region, where the two phases can coexist, the stress can have as many as three possible values

at one mean or nominal shear rate. The actual shear rates in each phase are, of course, lower and higher than the mean shear rate.

In conclusion, the existence of an entanglement network in surfactant solutions under certain conditions is a fact. While it seems likely that this network is formed by shear, this can only be shown deductively.

#### 3.9.2.4 Extensional Viscosity

High extensional viscosity has also been suggested as a cause of drag reduction by polymer additives [Landahl, 1977; Durst *et al.*, 1982; Hoyt, 1986; Bewersdorff and Thiel, 1993]. These researchers stated that the extensional viscosity of dilute polymer solutions can be large compared to that of the Newtonian solvent. This results in an additional resistance against vortex stretching and turbulent eddy growth, and leads to reduction of energy dissipation or drag reduction.

However, there are only a limited number of reports in the literature on extensional rheology for surfactant systems. Prud'homme and Warr [1994], using a Rheometrics RFX opposing nozzle rheometer, reported very high apparent extensional viscosities for the tetradecyl trimethyl ammonium salicylate (TTASal) aqueous system at concentrations of 15.3 mM and higher. These concentrations are much higher than those used in drag reduction studies, however. Wang *et al.* [1994] discussed the effect of elongational flow on micelles. They suggested that elongational flow is more effective than shear in causing coagulation of micelles. Lin *et al.* [1994] showed apparent extensional viscosity up to 400 poise for 20 mM cetyltrimethyl ammonium bromide (CTAB) with 14 mM 5-methylsalicylic acid as counterion. These concentrations are also much higher than those used in drag reduction studies. More recently, Lu *et al.* [1996a, c, d; 1997a, c; 1998], also using RFX, reported high apparent extensional viscosities on a number of drag reducing surfactant solutions at concentrations suitable for drag reduction applications. As mentioned above, one drag reducing surfactant system did not show normal viscoelastic behavior, but exhibited high apparent extensional viscosity [Lu *et al.*, 1997a, c].

In a turbulent pipe or channel flow, the strongest elongational fields exist in the buffer layer close to the wall, in which the fluid is already subjected to a shear gradient. This means that in order to understand the interaction between rheology and turbulence, which leads to drag reduction, the elongational behavior of the shear induced phase has to be known. A first attempt to estimate quantitatively the influence of pre-shearing on the elongational behavior of drag reducing dilute CTASal aqueous solutions was made by Vissmann and Bewersdorff [1990]. In their experiments the solutions were first subjected to a constant shear gradient in a Couette flow and then a small portion of the main Couette flow was directed to an orifice flow. The experimental results showed an increased elongational viscosity for the CTASal solutions when the pre-shear rate was in the critical range for the formation of the shear induced state. However, when these transient elongational viscosities were normalized by the shear viscosity at the pre-shear rate, this ratio was in the order of three, expected for Newtonian fluids below the critical shear rate for the shear induced state, a value that was also observed at high shear rates. The high shear rate result was attributed to destruction of micellar association formed in the shear induced state.

While surfactant drag reducers usually show shear viscosity no more than ten times that of water at high shear rates, most of them show unusually high extensional viscosity. In the bursting and growth of turbulent eddies, extensional motions dominate. High extensional viscosity increases the resistance of the fluid in the eddies to extensional flow and suppresses formation and growth of small scale eddies. Since dissipation of the high frequency energy in the bursting eddies is a major cause of energy loss in turbulent flow, the correlation of drag reduction and high extensional viscosity is not surprising. The data of Lu *et al.* [1997a, c] provide the first experimental demonstration that drag reduction and extensional viscosity coincide and drag reduction can occur in solutions which show no conventional viscoelastic behavior.

#### IV. APPLICATIONS OF SURFACTANT DRAG REDUCTION

Polymer drag reducers have had spectacular commercial success in increasing crude oil throughput in the Alyeska and in other pipelines [Burger *et al.*, 1982; Horn *et al.*, 1989]. However, even though surfactants are more promising than polymers in terms of stability in regions of high shear, applications for surfactant drag reducers have been limited to field tests in recirculation flows in district heating and cooling systems.

Zakin *et al.* [1971] explored the possibility of using CTAB/1-naphthol solution as a hydraulic transport medium. They found that the surfactant solution can not only reduce the pressure drop in transporting silica sand and plastic particles, but can also decrease the critical velocity (the minimum velocity to keep particles in suspension) of the flow. Despite these potential advantages, however, several problems were noted. The first problem was instability. The CTAB/1-naphthol solution degraded on aging and the interactions between the surface of the solid particles and the surfactant reduced the effective surfactant concentration. In addition, the high temperature limit for effective drag reduction was 48°C, which limits its use. These problems obviously make the use of CTAB/1-naphthol in hydraulic transport unlikely. Myska and Vocel [1977] studied another surfactant solution, the mixture of  $\alpha$ -naphthol and caraethoxipentadecyl-trimethylammonium bromide, in a suspension flow. They found that the larger the pipe, the greater the drag reduction. A limiting velocity was found, above which, the pressure drop increases sharply because of degradation of the micelles.

A promising application of surfactants as drag reducers is for use in district heating and cooling systems (DHC), in which hot water or cold water generated at a central station is circulated to buildings in a district. District heating systems are widely used in northern Europe and their use is expanding in the United States in such cities as Hartford, Trenton, Minneapolis, St. Paul, etc., and in Japan and Korea. They can utilize waste heat in power generating or cogenerating stations. As the cost of fuel increases, their use can be expected to expand in the U.S. By utilizing drag

reducers in such systems, pumping costs can be reduced to make the systems more efficient. The drag reducers used in such systems must be effective in the temperature ranges in the systems and they must be mechanically stable, due to the fact that the solution is circulated again and again, screening out the use of polymers. Several field tests using surfactants have been carried out in primary and secondary systems in Europe [Ohlendorf, 1985; Kleuker *et al.*, 1991; Hammer, 1991; Pollert *et al.*, 1994], Canada [Young, 1994] and the US [Rose *et al.*, 1984; Gasljevic and Matthys, 1996] with promising results.

The first field test of surfactants was by Rose *et al.* [1984] in a building system in Midland, Michigan, U.S., containing 6-inch pipes and fittings. Ohlendorf [1985] added surfactants to a small district heating system ( $D = 50$  mm) in Aachen, Germany, and achieved an overall drag reduction of 57% in the system. There was only slight reduction of the surfactant concentration due to adsorption of the surfactant on the inner walls of the system.

Later field tests in Völklingen, Germany [Kleuker *et al.*, 1991] and in Herning, Denmark [Hammer, 1991] showed significant drag reduction in primary sections of commercial district heating systems. Pollert *et al.* [1994] reported a field test of a surfactant drag reducer, Habon G, which was tested in a secondary system of a housing district heating system in the Czech Republic. They eliminated one of three system pumps after the addition of the surfactant and the system operated without any difficulties for a winter. Maximum pumping energy savings were over 40%. They concluded that surfactant drag reducers in the secondary system may not be as effective as in the primary system due to the greater number of singularities in the former. Surfactant was lost during the test, from leakage and from adsorption on the walls of the circulation systems, and re-addition of surfactant was needed. No significant reduction in heat transfer was observed. This was attributed to the high resistance of scale previously built up on the walls of heat exchanger tubes so that reduction in the surfactant solution heat transfer coefficient (increased resistance) had only a small effect on the overall heat transfer.

Young [1994] tested a surfactant drag reducer, 9-octadecen-bis(2-hydroxyethyl)-methyl-ammonium-3-methyl salicylate, over a 50-foot

long, 6-inch diameter pipe section in a 200-ton chillier water-based air conditioning system. Drag reduction over 70% was observed in the pipe over a temperature range of 5-10°C. No drag reduction was observed over the circulating pumps and control valves. Overall pressure drop was reduced by 40%. The discrepancy was due to the fact that the system contained many sharp pipe bends and diameter transitions on which the drag reducing additive had no effect. He concluded that the use of drag reducers is clearly more advantageous in systems involving liquid transport over substantial distances through straight pipes of uniform diameter. Overall heat transfer rate was reduced by 55% in the air coolers and 35% in the air cooling coils. The surfactant drag reducing system showed no deterioration over six months and no separation following a three week shutdown. He estimated that the payback period for the cost of the additives is less than two weeks based on the pumping power savings but the increased energy requirement of the chiller was not taken into account.

Gasljevic and Matthys [1996] reported their field test results in a building-size hydraulic cooling system. A reduction in pumping power of about 30% was achieved at the same flow rate. A reduction in pressure drop of 40% was measured in 6" elbows. The heat transfer reductions in the chiller's evaporator and in an air cooling coil were found to be 30% and 20%, respectively, whereas the drag reduction in the same units was 60% and 35%. Because of the increased power requirement of the chiller, there was no net power reduction [Matthys, 1998]. This was a particularly demanding test, however, as the power requirement of the chiller was ten times the power needed for pumping. In a second field test in which the micellar structure was destroyed at the entrance to the chilling section, thus enhancing the heat transfer, a net energy saving of 10% was achieved even in this extremely demanding application. In systems whose pumping energy and chiller energy requirements are comparable, larger net savings in energy should be attainable.

Steiff and Kloppe [1996] summarized the benefits of application of cationic surfactants as drag reducers in district heating systems (DHS). With the addition of surfactant drag reducers in existing DHS, pumping costs can

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be reduced, flow rate can be increased, the heat source can be shifted to waste heat, and supply temperature can be reduced by increasing the flow rate to obtain the same heat output. In addition, for application to new systems, smaller pipes and pumps can be used. They also summarized the requirements for surfactant drag reducers. Application problems do exist, however. Heat transfer is a major concern as heat transfer reduction can reach 70% or more in tube-tube exchangers. In plate heat exchangers, however, the reduction in heat transfer coefficients is much smaller [Christensen and Zakin, 1991; Hammer and Sorensen, 1993; Pollert *et al.*, 1996]. The influence of drag reducing flow on readouts of flow meters was also investigated by Steiff and Klopper [1996]. They found, due to the strong influence of drag reducers on turbulent flow, most common flow meters, such as impeller meters, orifice plates, venturi tubes and Pitot tube flow meters, do not produce correct readings of flow rate. Only magnetic inductive and ultrasonic (the type whose signal passes through the whole flow profile) meters can reliably be used to measure flow rates of drag reducing flows. They also mentioned that since the toxicity of Dobon G (similar to Habon G) is quite low, no additional treatment is needed in Germany, but environmental concerns have hampered commercial use of cationic surfactants in district heating systems in Germany and Scandinavia.

## V. SUMMARY

A considerable amount of research has been carried out on surfactant drag reduction. The usefulness of anionic soap surfactants as drag reducers is limited due to their sensitivity to cations in tap water. Nonionic surfactants, though their effective temperature ranges are limited, are potentially useful because of their chemical stability, rapid biodegradability and low toxicity. Zwitterionic surfactants may also be useful. Cationic surfactants with proper counterions have been identified to be the most effective surfactant drag reducers over a wide temperature range. Their drag reduction effectiveness is greatly dependent on the chemical structures and concentrations of surfactants and counterions, however. Surfactants with short alkyl chain are effective at low temperatures while long alkyl chains are effective at high

temperatures. Proper mixture of both can extend the effective temperature range to a very wide range.

Accompanying the reduction in momentum transfer, heat transfer is also reduced. Heat exchangers with flow channels which disturb the fluid more, such as plate exchangers, show less heat transfer reduction. Research is being carried out to minimize reduction in heat transfer by introducing micelle structure destroying devices at the entrances to the exchangers.

Surfactant drag reduction may exceed Virk's drag reduction asymptote for high polymers and velocity profiles may be steeper than his elastic sublayer asymptote. New drag reduction asymptotes for non-polymer drag reduction and for mean velocity profiles have been proposed. These imply that the mechanisms for drag reduction by high polymers and by surfactants may not be the same.

The details of the drag reduction mechanism are still unknown despite a large amount of research to clarify it, including turbulence measurements and rheological studies. It has been established that turbulence in the radial and tangential directions is suppressed by surfactant and high polymer drag reducers and zero Reynolds stress profiles have been observed for surfactants. Surfactant drag reducers may have some unusual rheological properties, including strong viscoelasticity and high extensional viscosity. However, not all surfactant drag reducers behave the same. In a few cases, drag reducing surfactants don't show viscoelastic characteristics.

Despite several successful field tests in district heating and district cooling systems, there are no commercial scale applications of surfactant drag reduction yet. Uncertainties regarding toxicity, long-term stability and post-application separation techniques have inhibited their widespread use.

Thus, further research to identify a stable, low toxicity, rapid biodegrading drag reducing surfactant system is needed. The effective temperature range can be tailored for a particular flow system's conditions. More fundamental research to clarify the drag reduction mechanism is also needed. Knowledge of the controlling properties for surfactant drag reduction will permit design and development of optimum drag reducing systems and permit prediction of the performance of drag reducers in any flow system.



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